U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-267 501

Preparations for Acquisition of Baseline Emissions Data from Gasoline Powered Trucks Between 6,000-lb & 10,000-lb GVW

Southwest Research Inst, San Antonio, Tex

Prepared for

National Air Pollution Control Administration, Ann Arbor, Mich Procedures and Emissions Background Development Section

Nov 68

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.

4. Title and Subtitle
Preparations for Acquisition of Baseline Emissions Data From Gasoline Powered Trucks Between 6,000-Lb and 10,000-Lb GVW

5. Report Date
November 1968

6.

7. Author(s)
Karl J. Springer and Glenn L. Williams

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78228

10. Project/Task/Work Unit No.

11. Contract/Grant No.
PH 86-67-72

12. Sponsoring Organization Name and Address
Procedures & Emissions Background Development Section
Motor Vehicle Research & Development Program
National Air Pollution Control Administration
Ann Arbor, Michigan 48105

13. Type of Report & Period Covered
Interim Report

14.

15. Supplementary Notes

16. Abstracts
The overall objective of this study is to obtain baseline emissions data from gasoline powered trucks using experimental, "second generation" type procedures. To acquire the baseline emissions data required, a substantial preparations phase involving further development of chassis dynamometer cycles, the design and construction of a truck version of the PHS Variable Dilution Sampler, and the establishment of correlation with previous program procedures, and different exhaust sampling schemes, are necessary. This interim report reviews and describes these preparations and procedures. The preparations phase for the given classification of trucks includes two major objectives: 1) to establish the relationship between emissions obtained on the simplified SwRI chassis dynamometer and the emissions octained by the Ethyl Corporation; 2) to confirm and establish correlation of exhaust gas sampling by the servoproportional sampling system and variable dilution sampling system.

17. Key Words and Document Analysis. 17a. Descriptors
Air Pollution
Motor Vehicles
Exhaust Gases
Trucks
Data Acquisition
Sampling
Preparation

17b. Identifiers/Open-Ended Terms
Emissions Data
Preparations Phase

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Available through NTIS, Springfield, VA.	UNCLASSIFIED	58
	20. Security Class (This Page) UNCLASSIFIED	22. Price PC A04 / MF A01

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

PB 267 501

PREPARATIONS FOR ACQUISITION OF BASELINE EMISSIONS DATA FROM GASOLINE POWERED TRUCKS BETWEEN 6,000-LB AND 10,000-LB GVW

by

Karl J. Springer

Glenn L. Williams

INTERIM REPORT

Prepared for

Procedures and Emissions Background Development Section
Motor Vehicle Research and Development Program
National Air Pollution Control Administration
Contract No. PH 86-67-72
U. S. Public Health Service
Department of Health, Education, and Welfare

November 1968

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO HOUSTON

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

58

SOUTHWEST RESEARCH INSTITUTE
8500 Culebra Road, San Antonio, Texas 78228

PREPARATIONS FOR ACQUISITION OF BASELINE EMISSIONS DATA FROM GASOLINE POWERED TRUCKS BETWEEN 6,000-LB AND 10,000-LB GVW

by
Karl J. Springer
Glenn L. Williams

INTERIM REPORT

Prepared for

Procedures and Emissions Background Development Section
Motor Vehicle Research and Development Program
National Air Pollution Control Administration
Contract No. PH 86-67-72
U. S. Public Health Service
Department of Health, Education, and Welfare

November 1968

Approved:

for John M. Clark, Jr., Director
Department of Automotive Research

TABLE OF CONTENTS

		Page
LIST OF ILLUSTRATIONS		iii
LIST OF TABLES		iv
I.	INTRODUCTION	1
II.	OBJECTIVE	2
III.	SAMPLING AND ANALYSIS EQUIPMENT, INSTRUMENTS AND PROCEDURES	3
	A. Continuous Sampling and Analysis	3
	B. PHS Servoproportional Exhaust Sampling System	3
	C. PHS Variable Dilution Sampling System	7
IV.	TEST VEHICLES AND EQUIPMENT	12
	A. Chassis Dynamometer Equipment and Operation	12
	B. Vehicle Tested	12
V.	CHASSIS DYNAMOMETER CYCLE PROCEDURES AND REVISIONS	15
	A. 1970 Federal Heavy-Duty Gasoline Truck Dynamometer Cycle	15
	B. Experimental Truck Chassis Dynamometer Cycles	15
VI.	EMISSION RESULTS	27
	A. Comparison of Experimental Cycle Results with DLA Road Course Data	27
	B. Correlation of Variable Dilution with Servo-proportional Sampler Results	30
	C. Federal Heavy-Duty Gasoline Truck Cycle	32
	D. Federal Heavy-Duty Gasoline Truck Cycle Using a Class IV Correlation Truck	35
VII.	SUMMARY AND CONCLUSIONS	37
LIST OF REFERENCES		39
APPENDICES		
	A. Class II Truck Exhaust Emission Results	40
	B. Class IV Truck Results for the 1970 Heavy-Duty Gasoline Truck Cycle	48

LIST OF ILLUSTRATIONS

Figure		Page
1	Continuous Sampling and Analysis System	4
2	Servoproportional Sampler Control Unit at Driver's Side and Servoproportional Sampler Unit with Sample Bag Container in Background	5
3	Class II Truck Equipped with Servoproportional Sampler Laminar Flow Element and Pressure Transducer	6
4	Bag Samples of Vehicle Exhaust Analyzed by Flame Ionization and Nondispersive Infrared Methods	8
5	Truck Version of the Variable Dilution Sampler	9
6	Total Exhaust Fed into Inlet Cone of Variable Dilution Sampler	10
7	Solid Disc Flywheel Inertia System Capable of Simulating 1, 500- to 16, 000-lb Inertia in 250-lb Increments	13
8	Effect of Road Load Dynamometer Setting on 1968 Stake Truck Emissions--Experimental Twelve-Mode Cycle	33

LIST OF TABLES

Table		Page
1	1970 Test Procedure Heavy-Duty Vehicles Dynamometer Operation Cycle	16
2	Dynamometer Cycle for Class II Trucks	17
3	Chassis Dynamometer Cycle for Class II Median Truck	18
4	SwRI Results with Ethyl Generalized Class II Cycle	19
5	SwRI Results with Class II Experimental Chassis Dynamometer Cycle	21
6	Comparison of Two Different Performing Vehicles with Class II Experimental Chassis Dynamometer Cycle	23
7	Experimental Class II Gasoline Truck Chassis Dynamometer Cycle	26
8	Comparison of Class II Twelve-Mode Experimental Cycle Emissions to Road Course (DLA) Emissions	28
9	Class II Gasoline Powered Truck Twelve-Mode Experimental Cycle Emissions	31
10	1970 Federal Standard Heavy-Duty Gasoline Truck Cycle Emissions	34
11	1970 Federal Standard Heavy-Duty Gasoline Truck Cycle Emissions	36

I. INTRODUCTION

The gasoline powered truck comprises about 10 percent of the total vehicles and burns approximately 25 percent of the gasoline consumed in the United States. A great deal of emissions data has been published on automobiles, but there is a significant lack of published emissions data from trucks. For this reason, the U. S. Public Health Service's National Center for Air Pollution Control initiated a study with Southwest Research Institute to acquire baseline emissions data. Because of the lead time requirements and the need to acquire baseline emissions data with "second generation" test procedures, the SwRI program was concerned mainly with emissions from vehicles operated on experimental chassis dynamometer cycles. The experimental cycles employed basically were those developed by an earlier U. S. PHS sponsored study at Ethyl Corporation and described in their final report[1]*. In addition to the use of experimental cycles which involved nonsteady-state engine operation, a special truck version of the new and novel exhaust gas sampling system developed by the U. S. Public Health Service was employed. The original prototype sampling system, known as the PHS Variable Dilution Sampler, was described in an APCA paper[2]. Part of the preparations phase of the SwRI program involved the design, construction, and calibration of a truck version of the automotive system and was described in a special SwRI report[3].

Therefore, this is an interim report of the efforts under way at Southwest Research Institute for the Procedures and Emissions Background Development Section of the NAPCA, U. S. PHS, under Contract PH 86-67-72. The report covers the preparations and initial emissions results obtained from a representative vehicle prior to the acquisition of baseline data from a number of vehicles between 6, 000 and 10, 000 GVW. The initial emissions results obtained using a chassis dynamometer are compared with previously obtained emissions data for similar vehicles operated on the Detroit-Los Angeles road course. Once this relationship was established using the PHS servoproportional sampler, experiments were conducted to relate the truck version of the PHS variable dilution sampler with the servoproportional sampler. Chassis dynamometer cycles included the proposed 1970 constant speed cycle, as well as several experimental variable speed cycles based on actual operation of trucks over urban routes.

*Superscript numbers in parentheses refer to List of References at the end of this report.

II. OBJECTIVE

The overall objective of the current studies at Southwest Research Institute is to obtain baseline emissions data from gasoline powered trucks using experimental, "second generation" type procedures and the most advanced emissions sampling and analysis procedures available. To acquire the baseline emissions data required, a substantial preparations phase involving further development of chassis dynamometer cycles, the design and construction of a truck version of the PHS Variable Dilution Sampler, and the establishment of correlation with previous program procedures, and different exhaust sampling schemes, are necessary.

This interim report is a review and description of the preparations phase for the acquisition of baseline emissions data from gasoline powered trucks, 6,000- to 10, 000-lb GVW. The preparations phase for the given classification of trucks includes two major objectives. The first is to establish the relationship between emissions obtained on the simplified SwRI chassis dynamometer and the emissions obtained by the Ethyl Corporation[1]. Due to the time elapsed between the two programs, a newer vehicle similar to a truck tested by Ethyl was used with the identical servoproportional type sampling system for the SwRI test. The second objective of the preparations phase is to confirm and establish correlation of exhaust gas sampling by the servoproportional sampling system and variable dilution sampling system. The intent of this investigation is to permit acquisition of baseline data from a number of truck configurations between 6, 000- and 10, 000-lb GVW.

III. SAMPLING AND ANALYSIS EQUIPMENT, INSTRUMENTS AND PROCEDURES

Three sampling and analysis systems were used to obtain meaningful exhaust emission data during the preparation phase of Class II trucks. The most familiar sampling and analysis system, the continuous sampler,[4, 5, 6] using the NDIR analytical system, is described first. The PHS servoproportional system[7], used to obtain all DLA road course exhaust emission data, is discussed next. The prototype truck version[3] of the newest sampling system, the variable dilution proportional sampler,[2] is also reviewed.

A. Continuous Sampling and Analysis

This exhaust gas sampling and analysis system (shown in the center of Fig. 1) which is specified under Federal regulations[8] is used for testing of spark-ignited, gasoline-fueled vehicles. A component description of the system includes a regulated exhaust gas flow rate through water condensate traps to four, rapid and continuous, nondispersive infrared (NDIR) gas analyzers. The analysis system consists of a carbon monoxide analyzer, 0 to 11 percent CO, a carbon dioxide analyzer, 0 to 16 percent CO_2, and two hydrocarbon analyzers, 0 to 1000 ppm HC and 0 to 10,000 ppm HC as normal (n) hexane (C_6H_{14}). The continuous analysis readout is accomplished almost instantaneously via two dual-pen strip chart recorders. The present system does not include instrumentation for the measurement of the oxides of nitrogen (NO_x); however, suitable NDIR instrumentation is available for the measurement of nitric oxide (NO). Shortcomings of the continuous system for surveillance testing include momentous data reduction; however, computers are helping to overcome this problem.

B. PHS Servoproportional Exhaust Sampling System

This exhaust gas sampling and analysis system has been used for several years to gain road course data for developing test cycles that would reproduce actual exhaust gas emission concentrations. The principle of operation permits the collection of a representative sample of exhaust gas in a moving vehicle by diverting and retaining a fixed percentage of the total airflow for later analysis.

A typical servoproportional sampler system is shown in Figures 2 and 3, connected to a vehicle undergoing a chassis dynamometer test. A sensitive differential pressure transducer is used to measure the pressure drop across the laminar flow element located in the carburetor air intake as shown in Figure 3. A similar pressure transducer measures the drop across a laminar flow unit in the sample flow line. The DC signal from the pressure transducers to the summing amplifier gives a resulting error

FIGURE 1. CONTINUOUS SAMPLING AND ANALYSIS SYSTEM

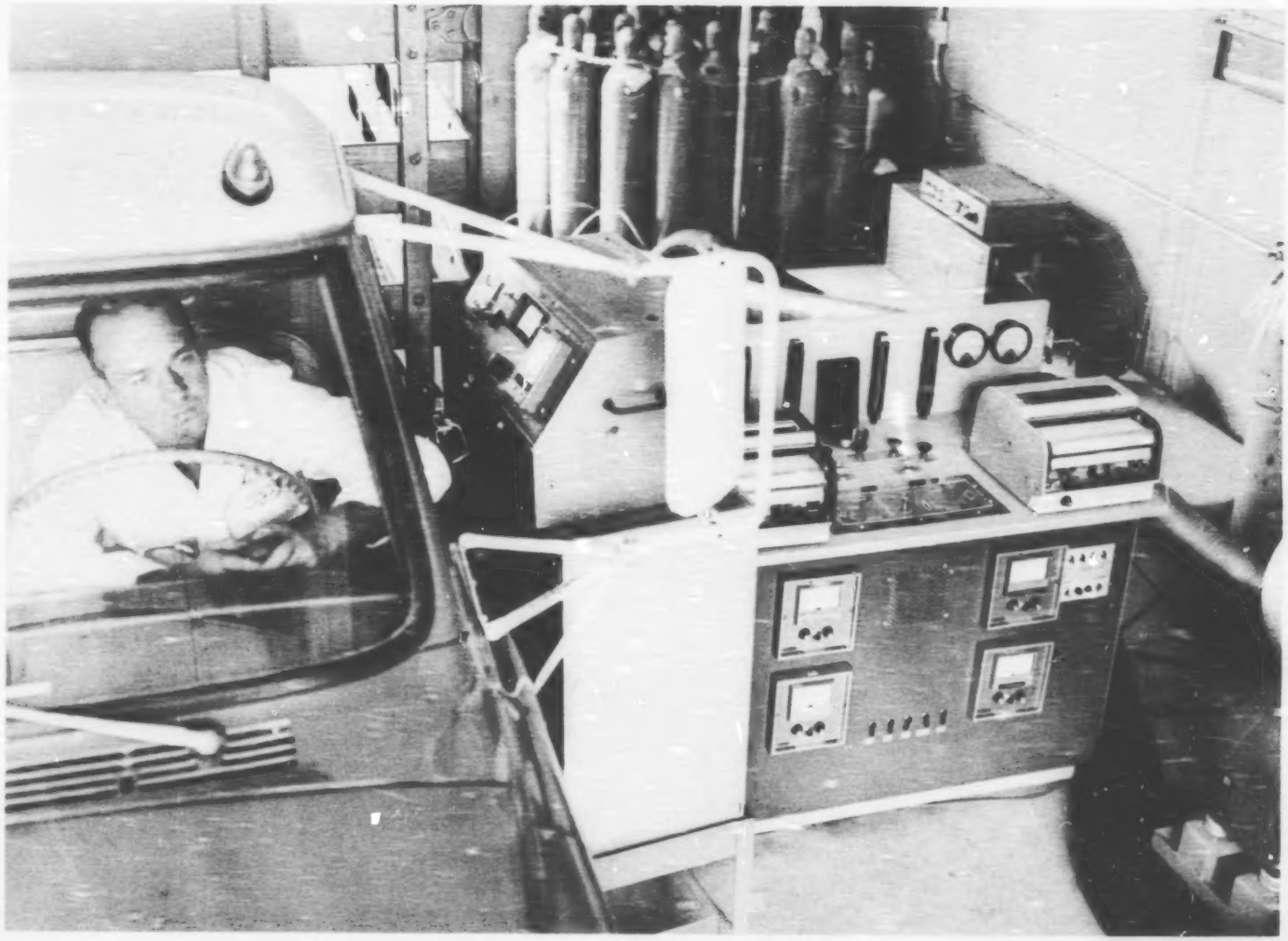

FIGURE 2. SERVOPROPORTIONAL SAMPLER CONTROL UNIT AT DRIVER'S SIDE AND SERVOPROPORTIONAL SAMPLER UNIT WITH SAMPLE BAG CONTAINER IN BACKGROUND

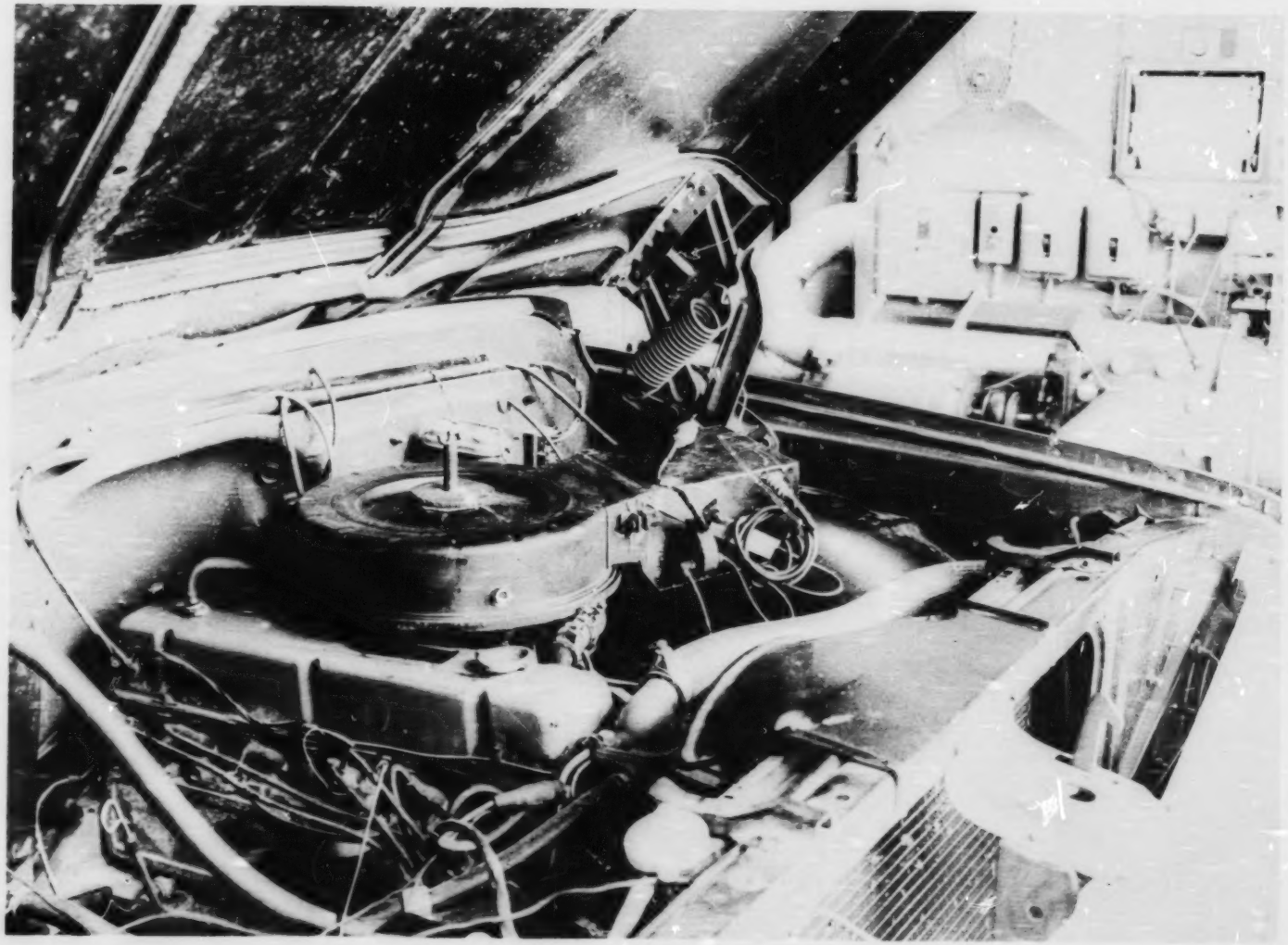

FIGURE 3. CLASS II TRUCK EQUIPPED WITH SERVOPROPORTIONAL SAMPLER LAMINAR FLOW ELEMENT AND PRESSURE TRANSDUCER

signal through a power amplifier that drives a control valve which meters the sample flow. By maintaining a zero error signal, the ratio of sample intake to exhaust is about 1 to 1000.

The 0.1-percent exhaust sample is collected throughout the test schedule in a Tedlar* bag, resulting in an integrated exhaust sample. This exhaust gas is prediluted with a fixed volume of nitrogen to "freeze" the exhaust gas. The fixed amount of diluent is accounted for in the calculation of mass emissions. The analysis of exhaust gases in the Tedlar bag requires a suitable array of NDIR instruments for measuring the CO, CO_2, and HC as n. hexane, and flame ionization detector (FID) to measure total hydrocarbons as shown in Figure 4. Measurement of the oxides of nitrogen is usually accomplished by means of the modified Saltzman syringe technique.

C. PHS Variable Dilution Sampling System

This sampling system is a recent PHS development using the inherent integrated bag sample technique. The sampler dilutes the total exhaust gas flow with ambient air such that a constant total flow results. The particular sampler used to gain gasoline truck baseline emissions was an enlarged version of the PHS automotive prototype in that the sampling system would handle the increased exhaust flow at higher temperatures emitted from truck-size engines. The resulting truck version of the variable dilution sampling system is shown in Figure 5. The total flow of exhaust gas and diluent air is pulled in through an inlet cone (shown in Fig. 6) that serves to reduce the inlet effects. The diluent sample flows through a flexible stainless steel pipe to the larger "U" shaped, air-to-exhaust, shell and tube, stainless steel heat exchanger. This heat exchanger serves as a heat sink for the moving exhaust gases; that is, the rapid exhaust gas temperature changes are reduced to a minimum so the mode changes are not seen at the inlet to the blower. The removal of the diluent sample by the isokinetic probe is just upstream of the two-speed, positive displacement pump. This two-speed pump gives the sampler the unique capability of operation of 950 cfm for the large truck-tractor gasoline engine and 625 cfm for medium-size gasoline truck engines (about three and two times the automotive capability, respectively). Regardless of the sampler system pump speed, a constant flow of 4 cfm is extracted from the main diluent sample line through a nickel-plated sample pump. This "split-off" of representative sample is deposited in a large 4- by 9-ft Tedlar* bag during the cyclic testing. All portions of the sampling system in contact with the diluent exhaust sample are fabricated of stainless steel and Teflon*. The description of the redesigned, repackaged, truck version of the variable dilution sampling system and the result of the calibration of this truck version were presented in a previous interim report[3] submitted under this program.

*E. I. duPont de Nemours and Company, Inc.

FIGURE 4. BAG SAMPLES OF VEHICLE EXHAUST ANALYZED BY FLAME IONIZATION AND NONDISPERSIVE INFRARED METHODS

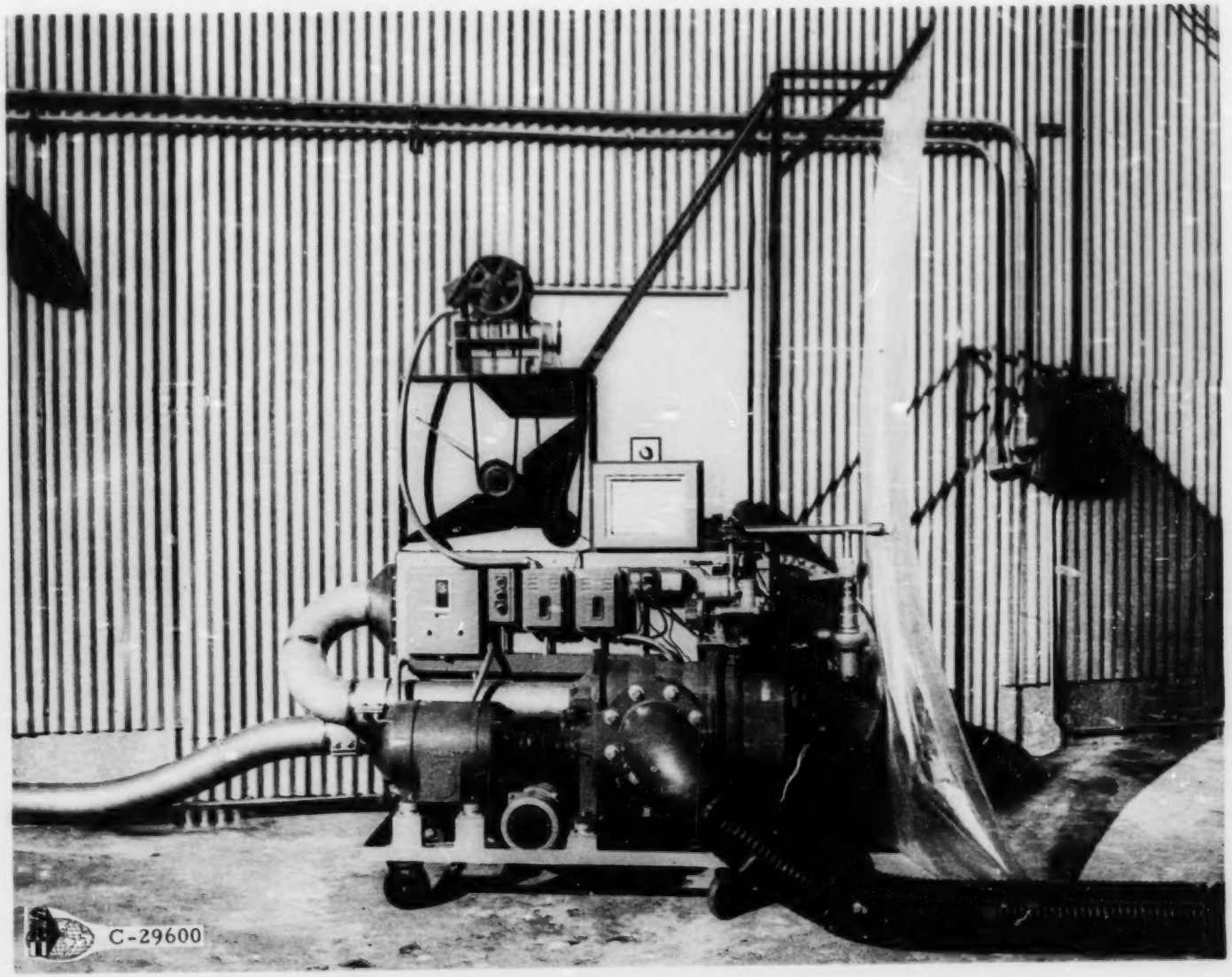

FIGURE 5. TRUCK VERSION OF THE VARIABLE DILUTION SAMPLER

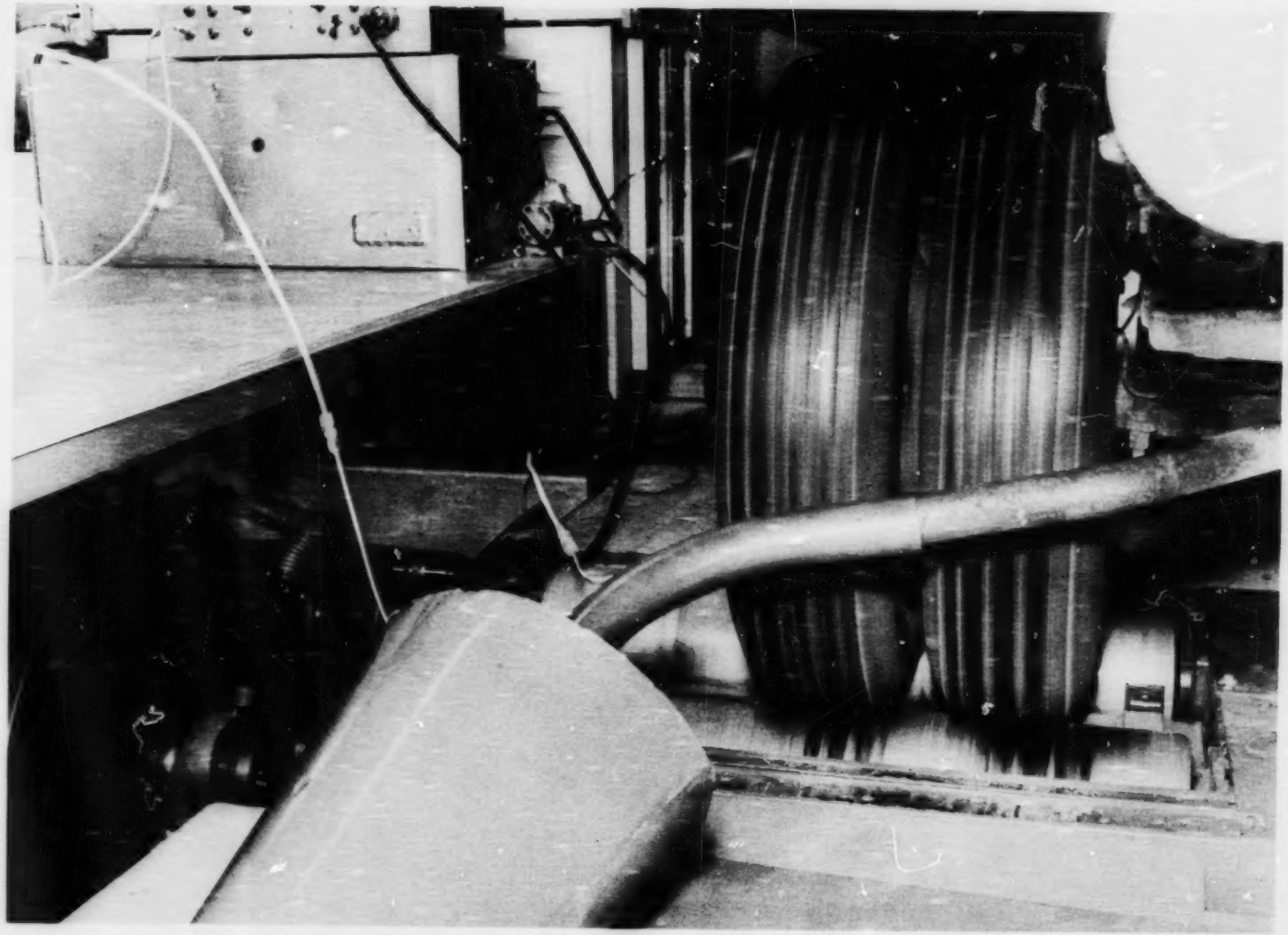

FIGURE 6. TOTAL EXHAUST FED INTO INLET CONE OF VARIABLE-DILUTION SAMPLER

The analytical procedure used with the variable dilution sampling is similar to the servoproportional sampler. A suitable array of NDIR instruments to measure CO, CO_2, and HC as n. hexane, and FIA instruments to measure total hydrocarbons as shown in Figure 4 is used. The oxides of nitrogen are measured using the modified Saltzman method. A small Tedlar transfer bag is used to bring the sample collected in the large Tedlar variable dilution sampler bag to the NDIR and FIA cart. An important factor that must be considered in analyzing the diluent exhaust gas sample from the variable dilution sample is the diluent air. In contrast with the nitrogen diluent which is free of contaminants, the large quantities of atmospheric air used as a diluent can contain hydrocarbons, carbon monoxide, and oxides of nitrogen; therefore, a background bag of air, taken during the run, must be analyzed. Using the ratio of air-to-exhaust as a means of weighting the background concentration, the additional concentration is subtracted out of the final analysis of the exhaust gas.

IV. TEST VEHICLES AND EQUIPMENT

Since one objective of this study is to relate actual road ccurse emissions to chassis dynamometer emissions, a discussion of the chassis dynamometer configuration used and the relation of the Class II vehicles tested ir the SwRI and Ethyl programs are presented.

A. Chassis Dynamometer Equipment and Operation

The SwRI system used in testing the Class II truck and presently being used for baseline Class III and IV trucks is a Clayton Series CT-200 single-axle, water brake, chassis dynamometer. Up to 200 hp may be absorbed by the water brake. This dynamometer is coupled to a solid disc flywheel arrangement shown in Figure 7. The flywheels can be coupled in such an arrangement that a minimum of 1, 500- to 16, 000-lb maximum equivalent inertia, with any 250-lb increment in between, can be simulated. This system also incorporates a 50-hp, three-phase, AC electric motor that can be used to maintain a constant speed operation as either a power absorbing or motoring unit. This motor can be readily disconnected via the motor slider mounts and a large timing belt. The characteristic of the SwRI chassis dyno unit is to follow the "q" load curve; i. e., it closely simulates the operation of a vehicle where load increases exponentially with increasing vehicle speed.

B. Vehicle Tested

The vehicle selected for initial familiarization and procedural development was not the same unit employed by Ethyl. This 1968, 10, 000-lb GVW Chevrolet truck powered by a 250-CID, inline six-cylinder engine was selected because of its low mileage and performance under a one-half payload road condition and was judged to be a representative Class II truck. The reason for not using a Class II truck tested by Ethyl was the time lapse of over 1 year. This lapse in time precluded valid correlations and comparisons as vehicle emissions can vary greatly with type and amount of operation and repair.

The 1968 Chevrolet stake side, single-axle truck was equipped with a four-speed transmission, 8. 25 × 20 tires, N/V ratio of 54. 8 with a tare weight of 4300 lb. This relatively new vehicle, with 6000 miles, had no emission control device. To facilitate the comparison with Ethyl work, the same model servoproportional sampler with large sample bag box was used. Other preparations to the vehicle included a minor tune-up of ignition (plugs, points, condenser, wires, distributor calibration) and carburetion. Idle speed and ignition timing were adjusted to factory specifications.

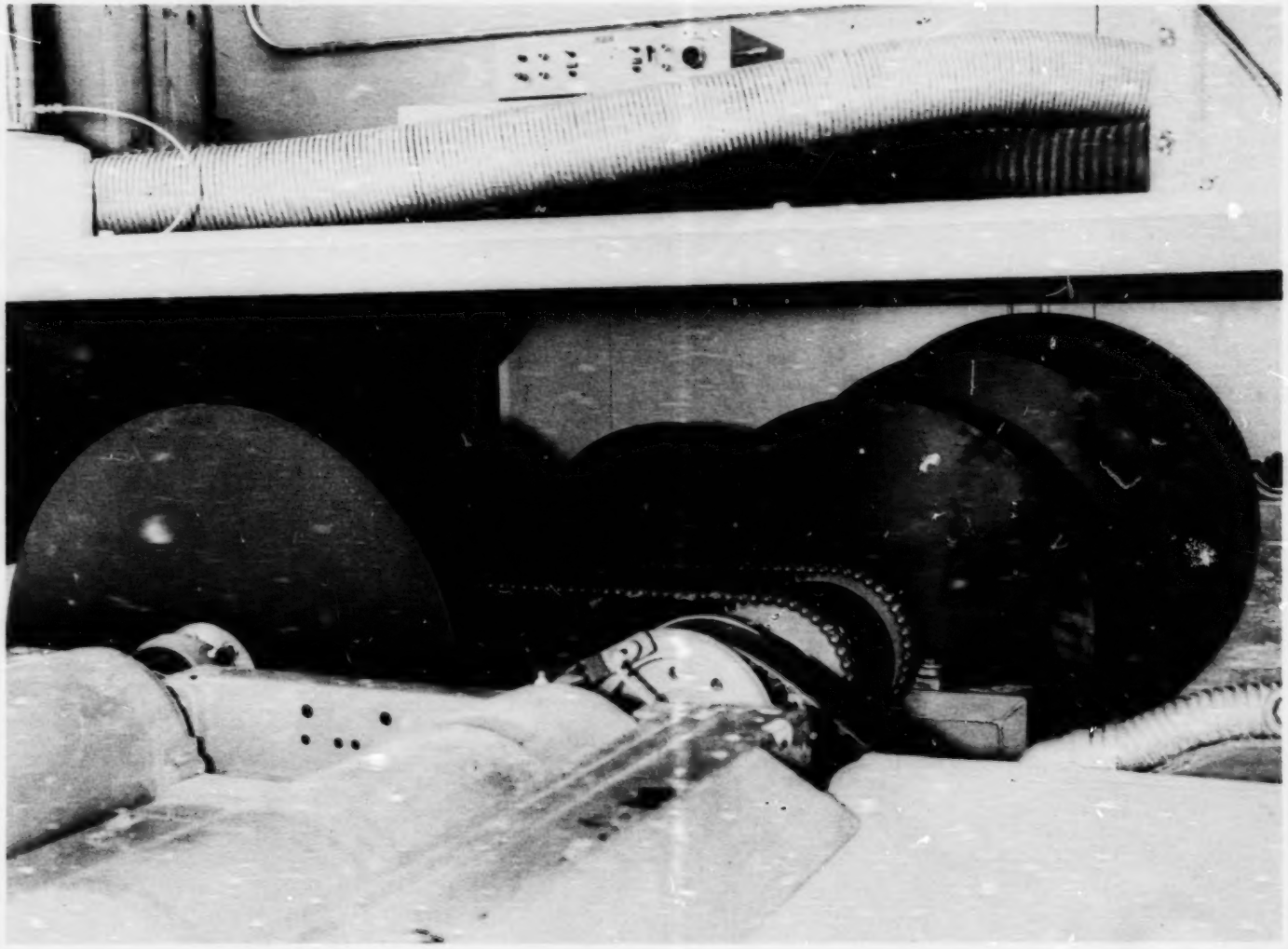

FIGURE 7. SOLID DISC FLYWELL INERTIA SYSTEM CAPABLE OF SIMULATING 1,500- TO 16,000-LB INERTIA IN 250-LB INCREMENTS

In an effort to evaluate the modified twelve-mode experimental cycle flexibility, an additional vehicle was evaluated. This truck, adjudged to be underpowered, was a 1963 Ford, 10, 000-lb GVW stake truck powered by a recently rebuilt 223-cu-in, six-cylinder engine. This vehicle, under level road conditions, was slower in response than the 1968 Chevrolet truck.

V. CHASSIS DYNAMOMETER CYCLE PROCEDURES AND REVISIONS

A description of procedures used in operating the Class II vehicle during the 1970 Federal, heavy-duty gasoline truck cycle and various experimental cycles is as follows.

A. 1970 Federal Heavy-Duty Gasoline Truck Dynamometer Cycle

This cycle consists of nine modes at essentially a constant engine speed of 2000 rpm, operated with a stationary engine dynamometer. The precise throttle setting and the mode-to-mode procedure is tabulated on Table 1, and the procedure is essentially the same as the California cycle[5]. All constant speed tests conducted by Ethyl and SwRI with the Class II trucks were done with the motoring chassis dynamometer. Constant speed was obtained by operating the complete vehicle on the SwRI chassis dynamometer previously described. By either power absorbing or motoring, the engine speed was maintained while changing the value of intake manifold vacuum. For example, the 19-in. Hg vacuum setting, sequence 5, is a part-throttle deceleration which requires dynamometer motoring. In operation, this cycle is repeated four times, with an idle mode prior to the first cycle and after the fourth cycle.

B. Experimental Truck Chassis Dynamometer Cycles

The generalized Class II truck schedule, proposed by Ethyl in their Final Report dated September 1967 under Contract PH 86-66-150, is included as Table 2. As with the generalized Class III and IV experimental cycles, the part-throttle shifting modes of the Class II cycle were found to be exceptionally difficult to operate. Incidentally, none of the Ethyl proposed cycles are based on a specified elapsed time for the cycle or mode duration times. For this reason, the Ethyl Class II Median Truck Cycle, shown on Table 3, was investigated with the SwRI Class II truck. This was the same approach used with the Class III and IV cycles. To use the words of the Ethyl report, "One truck in each weight group was selected on the basis of physical characteristics as being most representative of that group."

The truck selected for use in the initial SwRI studies, with the Project Officer's approval, was a 1968 Chevrolet, 10,000-lb GVW stake truck powered by 250-CID inline six-cylinder engine. The level road load at 30 mph in fourth gear with one-half payload was 5 hp at 16-in. Hg manifold vacuum. All chassis dynamometer tests were made with a simulation of 8000-lb vehicle weight, using the SwRI dynamometer-inertia facility. The success of operating the Ethyl Class II median truck cycle is indicated in Table 4. Difficulty was encountered during the mode 7 deceleration; the SwRI truck required 5 sec more to decelerate to 20 mph from 32 mph without applying brakes.

TABLE 1. 1970 TEST PROCEDURE HEAVY-DUTY VEHICLES
DYNAMOMETER OPERATION CYCLE

Sequence	Mode	Manifold Vacuum, in. Hg	Time in Mode, sec	Cumulative Time, sec
1	Idle		70	70
2	Cruise	16	23	93
3	PTA	10	44	137
4	Cruise	16	23	160
5	PTD	19	17	177
6	Cruise	16	23	200
7	FT	3	34	234
8	Cruise	16	23	257
9	CT		43	300

Engine dynamometer speed, 2000 ± 100 rpm.

An initial 5-min idle, two warm-up cycles and two hot cycles constitute a complete dynamometer run.

Note: The California procedure includes a provision for chassis dynamometer vehicle speed 25 ± 2 to 40 ± 2 mph to give engine speed close to 2000 rpm.

TABLE 2. DYNAMOMETER CYCLE FOR CLASS II TRUCKS
(Generalized Cycle Proposed by Ethyl)

Repeat for a Total of Four Cycles

Mode	Man. Vac, in. Hg	Rear-Wheels' Speed, mph	Engine, rpm	Duration, sec
1. Idle	(a)	0	(b)	22
2. Gear-1*	6	(c)	Idle-2300	(d)
3. Gear-2*	WOT	(c)	To 2200	(d)
4. Gear-3*	6	To 32	(c)	(d)
5. Decel	Closed Throttle	32-27	(c)	(e)
6. Accel	WOT	27-32	(c)	(d)
7. Decel	Closed Throttle	32-20	(c)	(g)
8. Accel	6	20-29	(c)	(g)
9. Cruise	(f)	29	(c)	22
10. Decel	Closed Throttle	29-19	(c)	(g)
11. Accel	8	19-29	(c)	(g)
12. Decel	Closed Throttle	29-0	To Idle†	(g)

(a) Not specified--idle mixture adjusted to give highest smooth-idle rpm.
(b) Manufacturer's specifications.
(c) Not specified--function of tire size and gear ratios.
(d) Not specified--varies with inertia load applied to equal road accel at 50 percent load.
(e) Not specified--normal decel against applied inertia load.
(f) Not specified--cruise load set to absorb 13.9 hp at rear wheels.
(g) Not specified--function of inertia and cruise loads at cruise load condition.

*Use gears 2, 3, 4 if four-speed transmission. On transmission with overdrive, overdrive is locked out.
†Declutch at 10-12 mph, and start timer for next idle mode.

TABLE 3. CHASSIS DYNAMOMETER CYCLE FOR CLASS II MEDIAN TRUCK*
(Ethyl Results of Median Truck on Generalized Cycle)

Repeat for a Total of Four Cycles

Vehicle: 1964 GMC 1502 Pickup GVW: 7500 lb
Engine: 305 CID, V-6 N/V: 48.7

Mode	Man. Vac, in. Hg	Rear-Wheels' Speed, mph	Engine, rpm	Duration, sec
1. Idle	(a)	0	(b)	22
2. Gear-1	6	0-16	Idle-2300	6
3. Gear-2	WOT	15-27	1250-2200	5
4. Gear-3	6	26-32	1250-1550	8
5. Decel	Closed Throttle	32-27	1550-1300	6
6. Accel	WOT	27-32	1300-1550	5
7. Decel	Closed Throttle	32-20	1550-950	5
8. Accel	6	20-29	950-1400	6
9. Cruise	16†	29	1400	22
10. Decel	Closed Throttle	29-19	1400-900	9
11. Accel	8	19-29	900-1400	5
12. Decel	Closed Throttle	29-0	1400-Idle‡	15

(a) Not specified--idle mixture adjusted to give highest smooth-idle rpm.
(b) Manufacturer's specifications.

*One truck in each weight group was selected on the basis of physical characteristics as being most representative of that group.
†Corresponds to 13.9 rear-wheel hp.
‡Declutch at 10-12 mph and start timer for next idle mode.

TABLE 4. SwRI RESULTS WITH ETHYL GENERALIZED CLASS II CYCLE

Repeat for a Total of Four Cycles

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6

GVW: 10,000 lb
N/V: 52.4

Mode	Man. Vac, in. Hg	Rear-Wheels' Speed, mph	Engine, rpm	Duration, sec	Cumulative Time, Min:Sec
1. Idle	(a)	0	(b)	22	22
2. Gear-1	6	0-16	Idle-2900	6	28
3. Gear-2	WOT	15-27	1400-2300	6	34
4. Gear-3	6	26-32	1450-1650	8	42
5. Decel	Closed Throttle	32-27	1650-1500	6	48
6. Accel	WOT	27-32	1400-1650	3	51
7. Decel	Closed Throttle	32-20	1650-1050	10	1:01
8. Accel	6	20-29	1050-1450	12	1:13
9. Cruise	16*	29	1450	22	1:35
10. Decel	Closed Throttle	29-19	1450-950	9	1:44
11. Accel	8	19-29	950-1450	16	2:00
12. Decel	Closed Throttle	29-0	1450-Idle†	15	2:15

(a) Not specified--idle mixture adjusted to give highest smooth-idle rpm.
(b) Manufacturer's specifications.

*Corresponds to 5 rear-wheel hp.
†Declutch at 10-12 mph, and start timer for next idle mode.

The following part throttle acceleration, mode 8, required 6 sec more than that required with the Ethyl median truck. Last, the part-throttle acceleration, mode 11, took 11 sec more on the SwRI facility. These additional mode times combine to make the cycle approximately 20 percent longer than the Ethyl median truck. No brakes were used during deceleration modes.

The initial adjustment to the cycle was to change all accelerations in gears 2, 3, and 4 (modes 2, 3, and 4) to WOT operation. Normal shifting between modes was employed as with the Class III and Class IV adjusted cycles, and the level road load, preset in the SwRI water brake type dynamometer was effective throughout the cycle. Also, the speed specifications (shown on Table 2) of 19 mph, modes 10 and 11, and 29 mph, modes 8 through 12, were changed for the sake of simplicity to 20 and 30 mph, respectively. This change was made at the request of the PHS Project Officer.

It was also requested that vehicle brakes be applied during the closed throttle deceleration modes, modes 5, 7, and 10, to determine if the times recorded by Ethyl for the median truck could be obtained with the SwRI Class II truck. It was found that no brakes were necessary during the mode 5 deceleration from 32 to 27 mph. However, heavy application of brakes was necessary during the mode 7 deceleration from 32 to 20 mph. To meet the Ethyl-reported 5-sec deceleration from 32 to 20 mph required not only heavy application of the vehicle brakes but immediate application after the completion of mode 6, a WOT acceleration. Operation of the vehicle and application of the brakes were termed "jerky" and not realistic of the way brakes would be applied in normal operation. Even with the fairly heavy application of brakes, it was found that operation with the slightly revised Class II Ethyl schedule still required 2:13 to complete. Modes 8 and 11, the long acceleration modes, continued to consume more time than was reported for the median Ethyl truck. This could be caused either by differences in dynamometers or in vehicle performance.

After some discussion with the Project Officer regarding the inability of the SwRI Class II truck to meet the reported overall cycle time of the Ethyl median truck, it was decided to adjust the individual modes which required excessive time in order that a 2-min overall cycle time be met. The resulting tentative cycle, outlined on Table 5, is described and compared to the Ethyl median truck results as follows. The 22-sec idle, mode 1, was maintained. As previously mentioned, modes 2 and 4 were changed to WOT setting to comply with the simplicity of driving the cycle through the shifting modes and to conform to the adjusted Class III and IV experimental cycles. A few seconds were gained with the WOT settings. The mode 5 median truck deceleration time of 6 sec was retained and treated as a maximum time as it is likely that some trucks can CT decelerate in less than 6 sec from 32 to 27 mph. No change was made to the 3-sec acceleration in mode 6 from 27 to 32 mph. The next deceleration, mode 7, duration was changed to 9 sec to conform to the similar mode 10 deceleration time of 9 sec (median truck).

TABLE 5. SwRI RESULTS WITH CLASS II EXPERIMENTAL CHASSIS DYNAMOMETER CYCLE*

Repeat for a Total of Four Cycles

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6

GVW: 10,000 lb
N/V: 52.4

Mode	Man. Vac, in. Hg	Rear-Wheels' Speed, mph	Engine, rpm	Duration, sec	Cumulative Time, Min:Sec
1. Idle		-	500	22	22†
2. Gear-2	WOT	0-16	500-2700	4	26
3. Gear-3	WOT	15-27	1700-2300	6	32
4. Gear-4	WOT	26-32	1500-1650	5	37
5. Decel (With brakes if necessary)	CT	32-27	1650-1400	6 (Do not exceed)	43
6. Accel	WOT	27-32	1400-1650	3	46
7. Decel (With brakes if necessary)	CT	32-20	1650-1050	9†	55
8. Accel	6	20-30	1050-1600	12	1:07
9. Cruise	Road Load‡	30	1600	22	1:29†
10. Decel (With brakes if necessary)	CT	30-20	1600-1050	9†	1:38
11. Accel	WOT	20-30	1050-1600	8	1:46
12. Decel	CT**	30-0	1600-0	14	2:00†

*As specified by R. Olsen and K. Springer per August 30, 1968, discussion.
**Declutch at 2:00 min, and allow engine to idle (start time for next cycle mode 1--use brakes to slow to stop).
†Time specified must be met.
‡For 250-CID Chevrolet, 10,000-GVW stake corresponds to 5 hp at 30 mph, 16 in. Hg.

Brakes were only required to be applied moderately during both long deceleration modes. The 6-in. Hg manifold vacuum part throttle acceleration, mode 8, was left as-is.

In conversations with the Project Officer, it was agreed that the Class II cycle should be similar to the Class III and IV experimental schedules in that a specified time should be met following the first cruise mode. To do this, the actual times required for modes 1 through 8, described above, were obtained with the SwRI Class II 1968 Chevrolet. These times were summed and the 22-sec cruise at 30 mph, mode 9, added to this sum to give a total cumulative time at the end of mode 9 of 1 min, 29 sec. As in the Class III and IV cycles, the mode 9 cruise serves to absorb any excess cumulative time which might occur during the first eight modes for a particular truck which cannot perform the same as the SwRI Class II truck.

Continuing with the description of the modifications made and referring to Table 5, the mode 10 extended deceleration from 30 to 20 mph was unchanged timewise. The 8-in. Hg vacuum acceleration from 20 to 30 mph was changed to a WOT operation mode to approach the 5-sec duration recorded by Ethyl for their median truck. It was found that the SwRI Class II truck operated at WOT required 8 sec to accelerate from 20 to 30 mph, resulting in a total cumulative time at the end of mode 11 of 1:46. In order to meet the objective of a 2-min overall cycle time, the mode 12 deceleration under closed throttle conditions is reached using a 14-sec duration. This is 1 sec less than that recorded with the Ethyl median truck (Table 3).

It is possible that some trucks may require more than 8 sec during the WOT acceleration, mode 11, which would result in a shorter mode 12 deceleration to result in an overall cycle time of 2 min. It should be mentioned that the overall cycle time is 6 sec longer than the cumulative time for the Ethyl median truck. Since the cycle is repeated four times, the operation is simplified by making each cycle an even number of minutes. As with the Class III and IV cycles, the mode 12 deceleration is under closed throttle conditions until the cumulative time specified of 2 min is reached. At this point, the vehicle is declutched, and the engine is allowed to idle. Time for the next 22-sec idle mode, mode 1, begins when the vehicle is declutched. With the vehicle declutched, brakes are applied to bring the rear wheels to rest in preparation for the acceleration through the gears.

The results of operation of a Class II truck with a smaller displacement engine than the 250-CID 1968 Chevrolet stake truck are listed on Table 6. The vehicle studied was a 1963 Ford 223-CID 10, 000-lb GVW stake truck. Both previously reported 1968 Chevrolet 250-CID and 1963 Ford 223-CID operational performances on the adjusted Ethyl Class II median truck cycle are listed to permit direct comparison of mode durations and cumulative times. The 1963 Ford stake truck powered by a smaller 223-CID, six-cylinder engine is judged an underpowered truck for 10, 000-lb GVW

TABLE 6. COMPARISON OF TWO DIFFERENT PERFORMING VEHICLES WITH CLASS II EXPERIMENTAL CHASSIS DYNAMOMETER CYCLE*

Repeat for a Total of Four Cycles

			Vehicle: 1968 Chevrolet Stake Engine: 250 CID, I-6 GVW: 10,000 lb		Vehicle: 1963 Ford Stake Engine: 223 CID, I-6 GVW: 10,000 lb	
Mode	Man. Vac. in. Hg	Rear-Wheels' Speed, mph	Duration, sec	Cumulative Time	Duration, sec	Cumulative Time, Min:Sec
1. Idle		-	22	22†	22	22†
2. Gear-2	WOT	0-16	4	26	6	28
3. Gear-3	WOT	15-27	6	32	8	36
4. Gear-4	WOT	26-32	5	37	8	44
5. Decel (With brakes if necessary)	CT	32-27	6 (Do not exceed)	43	6	50
6. Accel	WOT	27-32	3	46	6	56
7. Decel (With brakes if necessary)	CT	32-20	9†	55	9†	1:05
8. Accel	6	20-30	12	1:07	14	1:19
9. Cruise	Road Load‡	30	22	1:29†	10	1:29†
10. Decel (With brakes if necessary)	CT	30-20	9†	1:38†	9†	1:38†
11. Accel	WOT	20-30	8	1:46	14	1:52
12. Decel	CT**	30-0	14	2:00†	8	2:00†

*As specified by R. Olsen and K. Springer per August 30, 1968, discussion.
**Declutch at 2:00 min and allow engine to idle (start time for next cycle mode 1--use brakes to slow to stop).
†Time specified must be met.
‡For 250-CID Chevrolet, 10,000-GVW stake corresponds to 5 hp at 30 mph, 16 in. Hg.

rating. For the particular driveline arrangement, rear wheel response to a change in throttle setting of this vehicle under level road load conditions was definitely slower than the 1968 Chevrolet truck.

By reviewing the Class II experimental chassis dynamometer cycle, mode-by-mode, the performance of the underpowered Ford truck under cycle operation is readily indicated. Differences were found during all acceleration conditions as may be noted on Table 6. The first acceleration, mode 2, for the 1963 Ford truck took 2 sec longer to reach the 16-mph shifting point. The second acceleration, mode 3, also required an additional 2 sec to reach the shifting point of 27 mph. The third acceleration, mode 4, required 3 sec more with the underpowered truck. At the end of the acceleration through the gears, modes 2 through 4, the underpowered truck had required an additional 8 sec.

The deceleration, mode 5, duration is specified to not exceed 6 sec. Both truck duration times of 6 sec during this mode were met without applying brakes. The following WOT acceleration, mode 6, for the 1963 Ford truck required an additional 3 sec to meet the 27- to 32-mph speed increase. Mode 7 is a 9-sec deceleration from 32 to 20 mph. As with the 250-CID Chevrolet, the 223-CID Ford required moderate braking to keep from exceeding the 9-sec duration. The 6-in. Hg vacuum, part-throttle acceleration, mode 8, required 2 sec longer with the underpowered vehicle.

Mode 9 is the road load cruise mode which was suggested by Ethyl to be maintained at a duration time of 22 sec. However, this mode has become a makeup mode by specifying the total accumulative time at the end of mode 9 at 1 min and 29 sec. This time was met by both trucks, but the additional total time of 12 sec required during the various acceleration modes left only a 10-sec cruise with the underpowered truck.

The mode 10 deceleration, similar to mode 7, was met by the 223-CID Ford by moderate braking. The underpowered truck required an additional 6 sec to meet the acceleration from 20 to 30 mph, mode 11. The additional time of mode 11 is absorbed by the following deceleration, mode 12. Since the total elapsed time of the cycle is specified at 2 min, the final deceleration time of 8 sec was recorded.

Briefly then, all acceleration modes for the underpowered truck required more time to reach the given speed increase at the specified throttle setting. The total increase in time preceding the cruise, mode 9, was 12 sec. This time was made up by decreasing the length of the cruise mode. An additional 6 sec was made up during the CT deceleration, mode 12. In summary, the modifications made to the Class II schedule proposed by Ethyl appears to allow the operation of both a well performing as well as an underpowered vehicle without major changes. The reduction in cruise, mode 7, time is of concern as is the reduction in the last deceleration.

The overall result of the familiarization and procedural development studies, with the single Class II, 1968 Chevrolet truck, was to suggest a modified Ethyl cycle. This schedule, listed on Table 5 along with the 1968 Chevrolet operating results, is shown in Table 7 in a format similar to that of the Class III and IV schedules (see Reference 9 for the Class III and IV procedures). Accordingly, and with the agreement of the Project Officer, the schedule described on Table 7 was adopted for further study and possible use in acquiring baseline, Class II truck emissions.

TABLE 7. EXPERIMENTAL CLASS II GASOLINE TRUCK CHASSIS DYNAMOMETER CYCLE

Mode	Man. Vac. In. Hg.	Gear	Vehicle Speed, mph	Time, sec	
				Duration	Cumulative
1. Idle		N	0	22†	22†
2. Accel	WOT	2	0-16	-	-
3. Accel	WOT	3	15-27	-	-
4. Accel	WOT	4	26-32	-	-
5. Decel (With brakes if necessary)	CT	4	32-27	6 (Do not exceed)	43
6. Accel	WOT	4	27-32	-	-
7. Decel (With brakes if necessary)	CT	4	32-20	9†	-
8. Accel	6	4	20-30	-	-
9. Cruise	Road Load	4	30	-	89†
10. Decel (With brakes if necessary)	CT	4	30-20	9†	98†
11. Accel	WOT	4	20-30	-	-
12. Decel	CT‡	4	30-0	-	120†

Repeat above for total of four cycles, total time of 480 sec or 8 min.

*WOT is wide open throttle; CT is closed throttle.

†Time specified must be met.

‡Declutch at 120 sec and allow engine to idle (start time for next cycle, mode 1--use brakes to slow to stop).

VI. EMISSION RESULTS

For purposes of discussion, the emissions results are presented to first compare the experimental cycle to the Ethyl proposed results on similar but not identical vehicles. The next objective is to compare the results of the PHS servoproportional and variable dilution samplers to determine the level of correlation. Also discussed in this section are the results with the variable dilution sampler, as well as the continuous system, using the 1970 Federal, heavy-duty gasoline truck cycle procedure. In addition to the Class II truck results, additional data with a Class IV stake truck are included.

The emissions results are presented in tabular form and in order of their discussion in this section. The complete Class II emission results are tabulated in Appendix A in the following order: operation with the "second generation" experimental cycle using the servoproportional sampler to determine the effects of road load for comparison to previous work; second, correlation of servoproportional sampler to variable dilution sampler at various loading conditions; third, the emissions results obtained during the Federal cycle using the continuous and variable dilution sampling systems. Appendix B contains the Class IV truck emissions results for the Federal cycle.

A. Comparison of Experimental Cycle Results with DLA Road Course Data

With the formulation of a satisfactory tentative driving procedure, listed in Table 7, the SwRI Class II Chevrolet truck was equipped with the Pace servoproportional sampler. Intake air restriction via the laminar flow element compared closely to that with the stock air horn and air filter under a variety of constant speeds and loads. The vehicle was equipped with a calibrated distributor, new ignition wires, and spark plugs. Complete engine tune-up according to manufacturers specifications was accomplished. In addition to the servoproportional sampler, the truck version of the variable dilution sampling system was employed to obtain simultaneous exhaust samples for analysis. This approach shortened the time required to obtain servoproportional data for comparison to representative Ethyl Detroit-Los Angeles (DLA) road emissions and to compare servoproportional and variable dilution results on the SwRI Chevrolet truck.

Table 8 is a comparison of the exhaust emission values of three Chevrolet trucks powered by 250-CID inline six-cylinder engines. The emission data listed in the top portion of Table 8 were reported by Ethyl Corporation under PHS contract. Ethyl tested both the 1966 Chevrolet 10,000-lb GVW van and the 1966 Chevrolet 7,500-lb GVW pickup. Listed in

TABLE 8. COMPARISON OF CLASS II TWELVE-MODE EXPERIMENTAL CYCLE EMISSIONS TO ROAD COURSE (DLA) EMISSIONS

Vehicle Tested	Test Schedule, See Table	Cycle Operated	Cycle Loading	Sampling System	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel Avg	SCF/mi Exh	N/V Ratio	GVW
Ethyl Road and Chassis Results for Two Different Chev 250-CID Trucks Per Final Report (2-Run Average)													
66 Chev Van	-	DLA	Road	Servo	0.0322	0.0525	0.0128	0.3034	1.259	12.78	91.4	57.3	10,000
"	2	Ch. Dyn.	13.9 hp*	"	0.0266	0.0433	0.0083	0.3245	1.044	12.28	79.8	57.3	10,000
			Comparison Ratio		0.83	0.84	0.65	1.07	0.83	0.96	0.87		
66 Chev Pickup	-	DLA	Road	Servo	0.0206	0.0365	0.0146	0.1761	1.232	13.22	85.0	56.0	7,500
"	2	Ch. Dyn.	13.9 hp*	"	0.0168	0.0294	0.0207	0.1450	1.249	13.36	86.3	56.0	7,500
			Comparison Ratio		0.82	0.81	1.42	0.82	1.01	1.01	1.01		
SwRI Chassis Dynamometer Results for One Chev 250-CID Truck Vs Ethyl Road Data, 1966 Chev Pickup (SwRI Data are Averages of Seven Runs)													
66 Chev Pickup	-	DLA	Road	Servo	0.0206	0.0365	0.0146	0.1761	1.232	13.22	85.0	56.0	7,500
68 Chev Stake	7	Ch. Dyn.	Road Load†	"	0.0207	0.0402	0.0133	0.1827	1.133	12.94	89.9	52.4	10,000
			Comparison Ratio		1.01	1.10	0.91	1.04	0.92	0.98	1.06		
66 Chev Pickup	-	DLA	Road	Servo	0.0206	0.0365	0.0146	0.1761	1.232	13.22	85.0	56.0	7,500
68 Chev Stake	7	Ch. Dyn.	Road Load†	Var. Dil.	0.0202	0.0382	0.0194	0.2295	1.284	-	104.3	52.4	10,000
			Comparison Ratio		0.98	1.05	1.32	1.30	1.04	-	1.23		

*Vacuum not reported. For median truck, the cruise load at 29 mph was 16-in. Hg intake vacuum.
†Level road load at 30 mph was 5 hp at 16-in. Hg vacuum in 4th gear with one-half payload weight.

the lower portion of the table are emission results for the 1968 Chevrolet 10,000-lb GVW stake truck operated by SwRI. These results are compared to the Ethyl road DLA results for the 1966 pickup.

Since the objective of the experimental chassis dynamometer cycle is to produce emissions which represent realistic truck emissions in service, the original DLA road course emissions results are used for comparison purposes. A simple "comparison ratio" is used to indicate the magnitude of difference between the DLA road course emissions and the chassis dynamometer emissions data. Values greater than 1.0 indicate that chassis dynamometer cycle data are higher than road course data and values less than 1.0 indicate the opposite trend. A value of 1.0 indicates perfect correlation.

The first set of comparison ratios indicates the correlation between the 1966 Chevrolet van DLA road course and Ethyl chassis dynamometer emission data. As shown, the hydrocarbons, NO_x, CO_2, and engine airflow were somewhat lower than desired. This is indicated by an overall average comparison ratio of 0.86. The agreement between the Ethyl reported dynamometer cycle and the DLA emissions for the 1966 Chevrolet pickup were better as indicated by the total comparison ratio average of 0.98. The hydrocarbon emissions during the dynamometer cycle were low relative to the road course data; comparison ratio was 0.82.

Because of the time lapse and source, a suitable Class II truck, previously used by Ethyl, was not available to SwRI for experimentation purposes. Therefore, the DLA road course emissions data selected for comparison were the 1966 Chevrolet pickup data. Its N/V ratio was closer to the 1968 Chevrolet stake than was the Chevrolet van. The 1966 pickup also had less miles traveled than the 1966 van which corresponds closer to the relatively new 1968 stake truck with an odometer reading of 6000 miles. Finally, a much better correlation between original DLA and chassis dynamometer data was reported by Ethyl Corporation.

A comparison of the 1966 pickup DLA emissions to the results obtained with the SwRI 1968 Chevrolet operated under the Table 7 dynamometer schedule is shown in the lower portion of Table 8. An overall comparison ratio average of 1.01 is shown between the road course and experimental cycle using the Pace servoproportional sampling system. By coincidence, the level of hydrocarbon, NO_x, and CO agreement is better with the 1968 stake to the 1966 pickup DLA emissions than that with the Ethyl chassis dynamometer and DLA emissions data for the 1966 pickup.

In review, the experimental schedule of Table 7 appears to satisfactorily reflect the driving modes proposed by Ethyl. Operation of the SwRI vehicle on this schedule resulted in airflow which compared favorably with both Ethyl operated vehicles with the same make and size engine. By coincidence, exhaust emissions compared nicely with the DLA results for one of

the similar vehicles studied by Ethyl. This does not infer that operation of the SwRI vehicle under the Table 7 schedule represents correlation to the Ethyl work. Satisfactory correlation was previously established and reported for the Class III and IV vehicles. (Please refer to Interim Report: "Preparations for Acquisition of Baseline Emissions Data from Gasoline Powered Trucks Above 10,000-lb GVW" dated 12 June 1968.)

B. Correlation of Variable Dilution with Servoproportional Sampler Results

After the comparison of chassis dynamometer cycle results to similar road course data with the Class II vehicle, the next objective was to relate the results of variable dilution and servoproportional samples. This was a continuation of the Class III and IV studies previously reported[9]. The exhaust sampling was obtained simultaneously by both sampling systems. These results are tabulated in summary form on Table 9 and indicate the maximum, minimum, and average based on a minimum of four replicate runs. The correlation was made with the experimental twelve-mode cycle at road load conditions and two uphill loading conditions.

The trends of agreement for the variable dilution and servoproportional samplers were a bit erratic, but the specific corresponding values did not vary greatly. The following discussion will trace the particular emission results through the various preset loads. The road load hydrocarbon values essentially were equivalent, shown by comparison values of 1.0 and 0.96. The slight uphill hydrocarbon results by the variable dilution sampler were about 10 percent greater than the servoproportional results. This trend, however, was reversed with the uphill condition. The oxides of nitrogen values showed the greatest differences. The trend of higher NO_x values with the variable dilution sampler technique was not the same as that found in previous tests. The variable dilution NO_x results for the Class III and IV correlation trucks were lower than those found with the servoproportional sampler. No explanation can be made for this difference at this time. The CO and CO_2 mass emissions with the variable dilution sampler were also slightly higher than the servoproportional sampler results. The carbon monoxide mass emissions measured by the variable dilution technique is slightly higher than the servoproportional sampler during the three load conditions. The CO_2 emissions were also slightly higher with the variable dilution sampler measurement technique.

The physical measurement of engine exhaust airflow rate using the variable dilution sampler was not measured with the Class III and IV correlation trucks. To measure the exhaust flow, a continuous trace of the raw exhaust CO_2 concentration is monitored and integrated. With the known ratio of raw exhaust CO_2 to diluted sample CO_2 and the known volume ratio of total sampler flow, the exhaust gas flow rate can be calculated. This particular method appears to give higher exhaust flow rates than using the

TABLE 9. CLASS II GASOLINE POWERED TRUCK TWELVE-MODE EXPERIMENTAL CYCLE EMISSIONS*

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6

Fuel: Indolene
Cycle: Experiment Twelve-Mode

Run Condition	Vehicle Power Obs, hp	Proportional Sampling Method		NDIR UBHC, lb/mi	FIA UBHC, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel Avg	Exhaust Flow, SCF/mi
Level Road Load	5	Servo	Max	0.0235	0.0458	0.0148	0.2185	1.209	13.05	92.4
			Min	0.0185	0.0375	0.0117	0.1585	1.045	12.65	81.1
			Avg	0.0207	0.0402	0.0113	0.1827	1.133	12.94	89.8
		Variable Dilution	Max	0.0249	0.0419	0.0205	0.2355	1.380		112.5
			Min	0.0175	0.0360	0.0164	0.2180	1.130		94.3
			Avg	0.0202	0.0382	0.0192	0.2275	1.284		104.3
		Comparison Ratio		0.98	0.96	1.48	1.29	1.14		1.19
Slight Uphill Road Load	14	Servo	Max	0.0171	0.0357	0.0161	0.216	1.605	13.45	111.0
			Min	0.0161	0.0347	0.0149	0.202	1.440	13.05	109.5
			Avg	0.0164	0.0350	0.0156	0.211	1.491	13.20	110.6
		Variable Dilution	Max	0.0194	0.0391	0.0220	0.254	1.470		122.0
			Min	0.0179	0.0368	0.0152	0.238	1.460		115.0
			Avg	0.0186	0.0384	0.0169	0.250	1.470		119.3
		Comparison Ratio		1.13	1.10	1.08	1.18	0.99		1.08
Uphill Road Load	18	Servo	Max	0.0228	0.0433	0.0213	0.268	1.610	13.55	115.0
			Min	0.0199	0.0396	0.0172	0.241	1.335	13.40	113.0
			Avg	0.0215	0.0420	0.0190	0.250	1.483	13.50	114.1
		Variable Dilution	Max	0.0200	0.0394	0.0273	0.310	1.700		143.5
			Min	0.0182	0.0377	0.0222	0.296	1.665		136.4
			Avg	0.0190	0.0386	0.0245	0.304	1.683		139.2
		Comparison Ratio		0.88	0.92	1.29	1.21	1.13		1.22

*Supporting run data shown on Tables 1 through 4 of Appendix A.

more exact servoproportional sampler exhaust airflow measurement system (see results on Table 9).

An analysis of the exhaust emission trends using either or both sampling systems as a function of chassis dynamometer loading can be made from Figure 8. This figure graphically depicts the HC, CO, NO_x, CO_2 results listed in Table 9. Before discussing these trends, it should be noted that the effect of load is of importance mainly during the constant speed cruise portions of the experimental mode cycle.

The emission trends "track" well for the two sampling systems. One indicator is the engine exhaust flow which increases as the load increases. Of the two curves of exhaust flow in standard cubic feet per mile, the servoproportional sampler data are felt to be more reliable than that by the variable dilution method. The two sampling techniques showed an almost linear CO increase with load while the CO_2 leveled off at the slight uphill and uphill load condition. The hydrocarbon emissions measured by the NDIR instrument tracked well and went through a slight minimum at the slight uphill condition. The variable dilution FIA results were essentially unchanged by loading, while the servoproportional results go through a minimum at the slight uphill condition. The oxides of nitrogen also show contradictory trends. The variable dilution NO_x results go through a minimum at the slight uphill condition, while the servoproportional results increase linearly with load. In summary, it appears that the PHS servoproportional and variable dilution methods result in fairly similar emissions. As a consequence, the variable dilution method continues to show promise for acquisition of Class II baseline data.

C. Federal Heavy-Duty Gasoline Truck Cycle

The final series of experiments involving the Class II baseline truck was a series of tests using the Federal constant speed cycle with the recently installed SwRI chassis dynamometer. This dynamometer uses a 50-hp motor and is described in Section IV. The dynamometer procedure, presented in Table 1, was originally proposed as an either/or stationary or chassis dynamometer, nine-mode cyclic test. All SwRI data were taken simultaneously with a chassis dynamometer test using the continuous sampler and variable dilution sampler. Although the sampling systems were employed simultaneously, no attempt was made to correlate the final concentration level of the continuous system to the mass emissions results of the variable dilution system.

Table 10 is a tabulation of the exhaust emission results for the Federal cycle using both sampling systems. The top half of the table is a tabulation of the four-run average weighted HC and CO data taken with the continuous sampler. Comparing the average HC value of 348.9 ppm and the

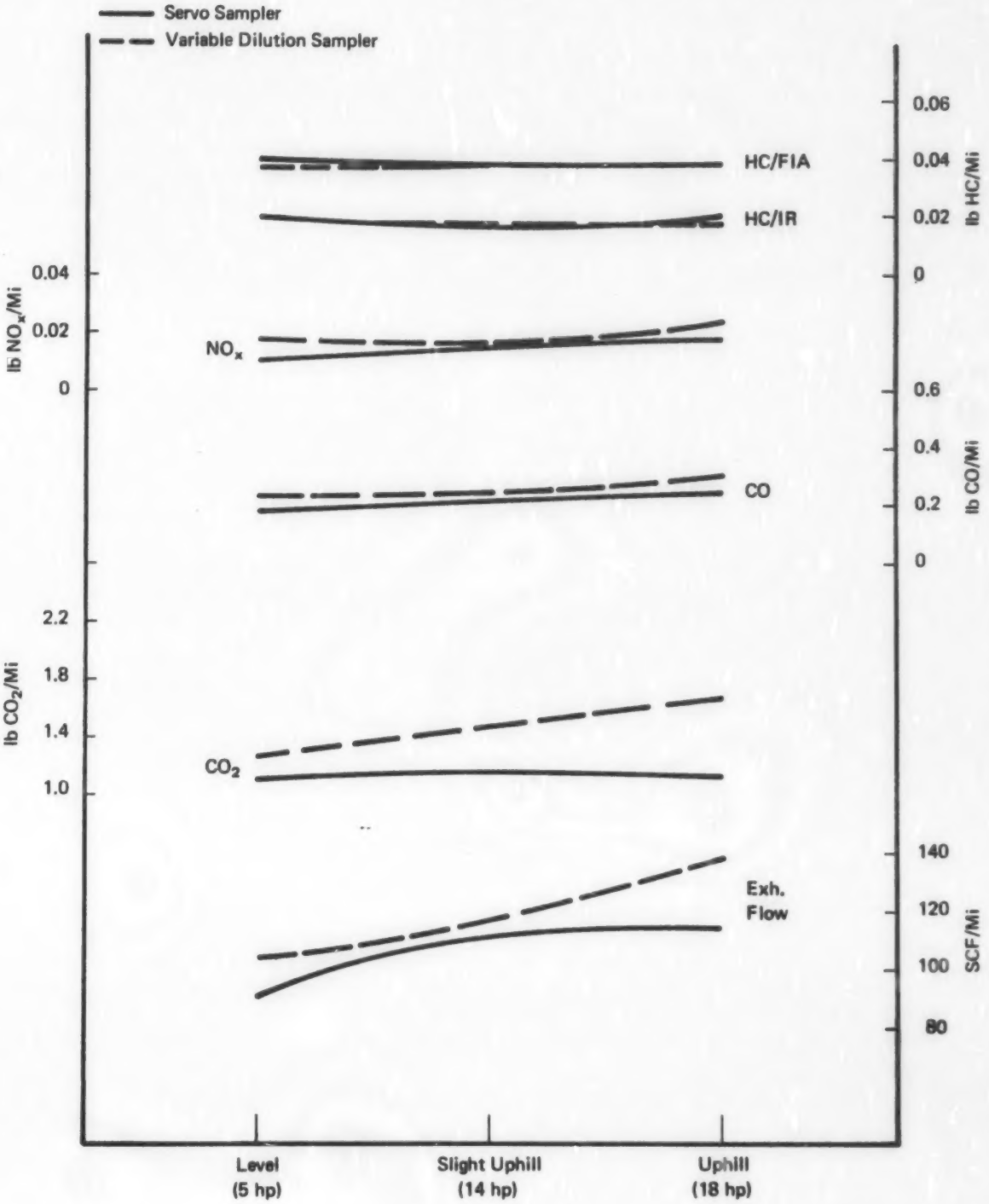

FIGURE 8. EFFECT OF ROAD LOAD DYNAMOMETER SETTING ON 1968 STAKE TRUCK EMISSIONS--EXPERIMENTAL TWELVE-MODE CYCLE

TABLE 10. 1970 FEDERAL STANDARD HEAVY-DUTY GASOLINE TRUCK CYCLE EMISSIONS

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID
Cycle: Federal
Fuel: Indolene

Continuous Sampling System*

HC/IR, ppm	CO/IR, %
348.9	2.73

PHS Variable Dilution System†

HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
0.00614	0.0124	0.0207	0.154	1.072	77.6

Comparison of Variable Dilution Results by Federal Constant Speed and Experimental Class II Cycles

Dynamometer Cycle	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
Federal	0.00614	0.0124	0.0207	0.154	1.072	77.6
Experimental	0.0202	0.0382	0.0192	0.2275	1.284	104.3

*See Table 5 of Appendix A for four-run results.
†See Table 7 of Appendix A for four-run results.

average CO value of 2.73 percent to the maximum Federal concentration limits of 275 ppm HC and 1.50 percent CO indicates that this particular, uncontrolled, 1968, 250-CID six-cylinder engine would not meet the standard. Federal cycle emissions data for a 250-CID, six-cylinder engine were not reported in the Ethyl final report. In the center portion of Table 10, emission results for the variable dilution system are listed. For heavy trucks, there is no currently recognized method for correlating mass emissions of the servoproportional sampling systems to the concentration results using the continuous sampling technique. These results may be valuable, however, in relating the experimental cycle results to the Federal cycle.

A comparison of the emission results using the Federal and experimental cycles is shown in the bottom portion of Table 10. The experimental cycle, which is intended to be representative of road emissions data, shows HC values via the variable dilution sampling system to be much higher than the Federal cycle results. CO and CO_2 emission levels are also higher with the experimental cycle. An interesting trend that was pointed out in the Class III and IV emission results and confirmed by the Class II trucks is the higher mass emission values of NO_x for the Federal cycle.

D. Federal Heavy-Duty Gasoline Truck Cycle Using a Class IV Correlation Truck

As stated in the emission results section of the Class III and IV interim report, difficulties were encountered in simulating the Federal cycle with the 1967 Chevrolet stake Class IV truck. This well-performing truck required both motoring and power absorbing capabilities that were not adequate at the time of writing the special report.[12] However, the new chassis dynamometer facility that was discussed in the equipment and operations section was available in July 1968 and the data gained with the Federal cycle are reported in this section.

The continuous and variable dilution sampler data for the Federal constant speed cycle test are presented in Table 11. The four-run average composite weighted HC value of 238.5 ppm and CO value of 1.52 percent can be compared to the Federal criteria of 275 ppm HC and 1.5 percent CO. The CO average is slightly over the requirement; however, a slight engine adjustment would probably bring the CO concentration below 1.5 percent. Shown next are the variable dilution emission results obtained at the same time as the continuous sampler results. No correlation with the continuous sampler average concentrations can be made at this time.

It is of interest, however, to compare the Federal with the experimental cycle results via the variable dilution sampler. This comparison is included on Table 11, and, as with the other correlation trucks, the experimental cycle hydrocarbon values are considerably more than the HC values of the Federal cycle. The other emission measurements, CO, NO_x, and CO_2, showed an opposite trend in that the Federal emission results were greater.

TABLE 11. 1970 FEDERAL STANDARD HEAVY-DUTY GASOLINE TRUCK CYCLE EMISSIONS

Vehicle: 1967 Chevrolet Stake
Engine: 366 CID, V-8
Cycle: Federal
Fuel: Indolene

Continuous Sampling System*

HC/IR, ppm	CO/IR, %
238.5	1.52

PHS Variable Dilution System†

HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
0.01042	0.0221	0.0278	0.144	2.261	154.

Comparison of Variable Dilution Results by Federal Constant Speed to Experimental Class IV Cycles

Dynamometer Cycle	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
Federal	0.01042	0.0221	0.0278	0.144	2.261	154.
Experimental Class IV (Level Road)	0.0207	0.0496	0.0249	0.122	2.050	-

*See Table 1 of Appendix B for four-run results.
†See Table 3 of Appendix B for four-run results.

VII. SUMMARY AND CONCLUSIONS

The following summarizes the important aspects of the preparations phase of this study of baseline gasoline trucks between the gross vehicle weights of 6,000 to 10,000 lb. These remarks are made as a result of a study of a representative Class II truck emissions obtained by three sampling systems and with various chassis dynamometer test procedures:

(1) A number of chassis dynamometer cycles were employed to investigate the exhaust emission results as well as to determine the operative characteristics of the representative truck. These cycles included a chassis dynamometer version of the nine-mode, constant speed, heavy-duty gasoline truck cycle and several versions of an experimental mode cycle with various road load simulations. The "second generation" of the experimental cycle which evolved at SwRI appears to produce realistic exhaust emission results that are representative of road course results. The operational success and the repeatability of the experimental cycle tend to justify its use in obtaining baseline emission results.

(2) Exhaust emission results with similar Class II trucks showed a satisfactory comparison between DLA road course data and the experimental cycle data at level road. Experimental cycle emission result trends were also shown with two other power settings; slight uphill and uphill. Overall, the level road load experimental cycle appears to more closely correspond to the road course data than the other conditions studied.

(3) The level of agreement between the variable dilution and servoproportional sampling systems emission results was generally satisfactory. Hydrocarbons and NO_x values were not consistent with variations in load. The variable dilution CO value was consistently slightly higher, while the CO_2 value was lower than the servoproportional results.

(4) As with tests using the Class III and IV cycles, the prototype truck version of the variable dilution system was readily sensitive to changes in vehicle operation with the Class II cycle test. This further justifies acquisition of baseline data by this method.

(5) Exhaust emission results were obtained using a chassis dynamometer version of the 1970 Federal Heavy-Duty Gasoline Truck Cycle. Emission samples were taken via the continuous sampler and the variable dilution sampler. Since no readily apparent method for trucks is available for expressing equivalent mass emissions for the continuous sampler, no correlation is possible.

(6) The Federal cycle mass emission data from the Class II correlation truck and the Class IV vehicle does not correlate with dynamometer test cycles that were established to simulate actual vehicle operation.

LIST OF REFERENCES

1. "Exhaust Emission Analysis and Mode Cycle Development for Gasoline Powered Trucks," Ethyl Corporation Final Report to U.S. Public Health Service, Contract PH 86-66-150, September 1967.

2. Broering, Louis; Werner, William; and Rose, Andrew, "Automotive Mass Emission Analysis by a Variable Dilution Technique," presented at the Air Pollution Control Association Annual Meeting, Cleveland, Ohio, June 1967.

3. Springer, Karl; and Williams, Glenn L., "Preparation of Truck Version PHS Variable Dilution Sampling System," Special Report to U.S. Public Health Service, Contract PH 86-67-72, March 1968.

4. Federal Register, Vol. 33, No. 2, Part II, Department of Health, Education and Welfare, January [illegible], 1968.

5. "California Test Procedure and Criteria for Motor Vehicle Exhaust Emission Control," California Motor Vehicle Pollution Control Board, 417 South Hill Street, Los Angeles, California 90013.

6. Federal Register, Vol. 31, No. 61, Part II, Department of Health, Education and Welfare, March 30, 1966.

7. Smith, R.; Rose, A. H.; and Kruse, R., "An Auto-Exhaust Proportional Sampler," International Journal of Air and Water Pollution, Vol. 8, pp. 427-440 (1964).

8. Federal Register, Vol. 33, No. 108, Part II, Department of Health, Education, and Welfare, June 4, 1968.

9. Springer, Karl J; and Williams, Glenn L., "Preparations for Acquisition of Baseline Emissions Data from Gasoline Powered Trucks Above 10,000-lb GVW," Interim Report, Contract PH 86-67-72, June 1968.

APPENDIX A

CLASS II TRUCK EXHAUST EMISSION RESULTS

TABLE A.1. CLASS II EXHAUST EMISSIONS FOR COMPARISON WITH DLA ROAD COURSE RESULTS

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6
Date: September 6-9, 1968

Cycle: Experimental Twelve-Mode
Sampler: Servoproportional
Fuel: Indolene

Load Condition	Run No.	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel, CO	Air/Fuel, CO_2	Air/Fuel, Avg	Exhaust Flow, SCF/mi
Level	1	7090	13,800	1345	2.74	11.42	0.0235	0.0458	0.0148	0.1840	1.209	13.60	12.50	13.05	92.4
	2	6100	11,850	1260	2.76	11.30	0.0201	0.0391	0.0138	0.1835	1.185	13.60	12.45	13.05	91.9
	3	6450	12,000	1085	2.42	11.03	0.0208	0.0388	0.0117	0.1585	1.135	13.70	12.30	13.00	90.0
	4	6520	13,600	1290	2.98	11.80	0.0190	0.0396	0.0125	0.1760	1.095	13.50	12.80	13.15	81.1
	5	5640	11,400	1230	3.29	10.65	0.0185	0.0375	0.0134	0.2185	1.115	13.40	12.10	12.75	91.5
	6	6260	11,880	1235	2.55	11.00	0.0206	0.0390	0.0135	0.1700	1.150	13.70	12.30	13.00	91.4
	7	6950	12,800	1140	3.01	10.10	0.0224	0.0416	0.0134	0.1985	1.045	13.50	11.80	12.65	90.5
	Max	7090	13,800	1345	3.29	11.80	0.0235	0.0458	0.0148	0.2185	1.209	13.70	12.80	13.15	92.4
	Min	5640	11,400	1085	2.42	10.10	0.0185	0.0375	0.0117	0.1585	1.045	13.40	11.80	12.65	81.1
	Avg	6430	12,476	1227	2.82	11.04	0.0207	0.0402	0.133	0.1827	1.133	13.57	12.32	12.94	89.8
Slight Uphill	1	4160	8,740	1200	2.65	11.40	0.0164	0.0349	0.0159	0.213	1.440	13.60	12.50	13.05	111.0
	2	4340	9,060	1140	2.54	11.65	0.0171	0.0357	0.0149	0.202	1.460	13.70	12.65	13.17	109.5
	3	4040	8,730	1210	2.71	12.64	0.0161	0.0349	0.0161	0.214	1.605	13.70	13.20	13.45	111.0
	4	4040	8,680	1170	2.68	11.55	0.0161	0.0347	0.0155	0.216	1.460	13.65	12.60	13.12	111.0
	Max	4340	9,060	1210	2.71	12.64	0.0171	0.0357	0.0161	0.216	1.605	13.70	13.20	13.45	111.0
	Min	4040	8,680	1140	2.54	11.40	0.0161	0.0347	0.0149	0.202	1.440	13.60	12.50	13.05	109.5
	Avg	4145	8,803	1180	2.65	11.81	0.0164	0.0350	0.0156	0.211	1.491	13.66	12.74	13.20	110.6
Uphill	1	4810	9,550	1249	2.94	10.14	0.0199	0.0396	0.0172	0.246	1.335	13.55	11.80	12.88	115.0
	2	5600	10,880	1380	3.26	10.97	0.0228	0.0433	0.0187	0.268	1.425	13.40	12.30	12.85	113.2
	3	5265	10,310	1550	2.91	11.85	0.0218	0.0428	0.0213	0.244	1.560	13.55	12.80	13.12	115.0
	4	5250	10,390	1400	2.93	12.45	0.0214	0.0422	0.0189	0.241	1.610	13.50	13.10	13.30	113.0
	Max	5600	10,880	1550	3.26	12.45	0.0228	0.0433	0.0213	0.268	1.610	13.55	13.10	13.30	115.0
	Min	4810	9,550	1249	2.91	10.14	0.0199	0.0396	0.0172	0.241	1.335	13.40	11.80	12.85	113.0
	Avg	5231	10,283	1395	3.01	11.35	0.0215	0.0420	0.0190	0.250	1.483	13.50	12.50	13.04	114.1

TABLE 2. CLASS II EXHAUST EMISSIONS LEVEL ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6
Date: September 5, 1968

Cycle: Experimental Twelve-Mode
Fuel: Indolene

Run No.	Sampler	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel, CO	Air/Fuel, CO_2	Air/Fuel, Avg	Exhaust Flow, SCF/mi
1	Proportional	7090	13,800	1345	2.74	11.42	0.0235	0.0458	0.0148	0.1840	1.209	13.60	12.50	13.05	92.4
2		6100	11,850	1260	2.76	11.30	0.0201	0.0391	0.0138	0.1835	1.185	13.60	12.45	13.05	91.9
3		6450	12,000	1085	2.42	11.03	0.0208	0.0388	0.0117	0.1585	1.135	13.70	12.30	13.00	90.0
4		6520	13,600	1290	2.98	11.80	0.0190	0.0396	0.0125	0.1760	1.095	13.50	12.80	13.15	81.1
5		5640	11,400	1230	3.29	10.65	0.0185	0.0375	0.0134	0.2185	1.115	13.40	12.10	12.75	91.5
6		6260	11,880	1235	2.55	11.00	0.0206	0.0390	0.0135	0.1700	1.150	13.70	12.30	13.00	91.4
7		6950	12,800	1140	3.01	10.10	0.0224	0.0416	0.0134	0.1985	1.045	13.50	11.80	12.65	90.5
Max		7090	13,800	1345	3.29	11.80	0.0235	0.0458	0.0148	0.2185	1.209	13.70	12.80	13.15	92.4
Min		5640	11,400	1085	2.42	10.10	0.0185	0.0375	0.0117	0.1585	1.045	13.40	11.80	12.65	81.1
Avg		6430	12,476	1227	2.82	11.04	0.0207	0.0402	0.0133	0.1834	1.133	13.57	12.32	12.95	89.8
1	Variable Dilution	330	570	92.5	0.170	0.60	0.0197	0.0379	0.0204	0.2280	1.380				104.5
2		310	550	92.5	0.175	0.60	0.0175	0.0360	0.0190	0.2320	1.350				100.0
3		380	630	84.9	0.165	0.60	0.0249	0.0419	0.0187	0.2220	1.269				109.5
4		340	610	92.5	0.170	0.60	0.0220	0.0402	0.0203	0.2260	1.258				108.5
5		320	590	75.0	0.175	0.65	0.0185	0.0360	0.0164	0.2310	1.360				112.5
6		340	610	92.5	0.165	0.60	0.0194	0.0388	0.0205	0.2180	1.240				100.5
7		330	610	92.5	0.180	0.55	0.0196	0.0363	0.0188	0.2355	1.130				94.3
Max		380	630	92.5	0.180	0.65	0.0249	0.0419	0.0205	0.2355	1.380				112.5
Min		310	550	75.0	0.165	0.55	0.0175	0.0360	0.0164	0.2180	1.130				94.3
Avg		336	597	88.9	0.171	0.60	0.202	0.0382	0.0192	0.2275	1.284				104.3

Note 1: Variable dilution concentration values are not adjusted for diluent air contamination. Mass emissions as lb/mi are adjusted for influence of background.

TABLE A. 3. CLASS II EXHAUST EMISSIONS - SLIGHT UPHILL ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHODS

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6
Date: September 6, 1968

Cycle: Experimental Twelve-Mode
Fuel: Indolene

Run No.	Sampler	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/ Fuel, CO	Air/ Fuel, CO_2	Air/ Fuel, Avg	Exhaust Flow, SCF/mi
1	Proportional	4160	8740	1200	2.65	11.40	0.0164	0.0349	0.0159	0.213	1.440	13.60	12.50	13.05	111.0
2		4340	9060	1140	2.54	11.65	0.0171	0.0357	0.0149	0.202	1.460	13.70	12.65	13.17	109.5
3		4040	8730	1210	2.71	12.64	0.0161	0.0349	0.0161	0.214	1.605	13.70	13.20	13.45	111.0
4		4040	8680	1170	2.68	11.55	0.0161	0.0347	0.0155	0.216	1.460	13.65	12.60	13.12	111.0
Max		4340	9060	1210	2.71	12.64	0.0171	0.0357	0.0161	0.216	1.605	13.70	13.20	13.45	111.0
Min		4040	8680	1140	2.54	11.40	0.0161	0.0347	0.0149	0.202	1.440	13.60	12.50	13.05	109.5
Avg		4145	8803	1180	2.65	11.81	0.0164	0.0350	0.0156	0.211	1.491	13.66	12.74	13.20	110.6
1	Variable Dilution	330	590	100.0	0.19	0.70	0.0181	0.0389	0.0220	0.254	1.470				115.0
2		330	600	69.4	0.19	0.70	0.0188	0.0391	0.0152	0.254	1.470				121.0
3		350	590	69.4	0.19	0.70	0.0194	0.0389	0.0152	0.254	1.470				122.0
4		330	570	69.4	0.18	0.70	0.0179	0.0368	0.0152	0.238	1.460				119.0
Max		350	600	100.0	0.19	0.70	0.0194	0.0391	0.0220	0.254	1.470				122.0
Min		330	570	69.4	0.18	0.70	0.0179	0.0368	0.0152	0.238	1.460				115.0
Avg		335	588	77.1	0.19	0.70	0.0186	0.0384	0.0169	0.250	1.470				119.3

Note: Variable dilution concentration values are not adjusted for dilute air contaminations.
Mass emissions as lb/mi are adjusted for influence of background.

TABLE A.4. CLASS II EXHAUST EMISSIONS - UPHILL ROAD LOAD CORRELATION OF SERVOPROPORTIONAL WITH VARIABLE DILUTION METHOD

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6
Date: September 9, 1968

Cycle: Experimental Twelve-Mode
Fuel: Indolene

Run No.	Sampler	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Air/Fuel, CO	Air/Fuel, CO_2	Air/Fuel, Avg	Exhaust Flow, SCF/mi
1	Proportional	4810	9,550	1249	2.94	10.14	0.0199	0.0396	0.0172	0.246	1.335	13.55	11.80	12.88	115.0
2		5600	10,880	1380	3.26	10.97	0.0228	0.0433	0.0187	0.268	1.425	13.40	12.30	12.85	113.2
3		5265	10,310	1550	2.91	11.85	0.0218	0.0428	0.0213	0.244	1.560	13.55	12.80	13.12	115.0
4		5250	10,390	1400	2.93	12.45	0.0214	0.0422	0.0189	0.241	1.610	13.50	13.10	13.30	113.0
Max		5600	10,880	1550	3.26	12.45	0.0228	0.0433	0.0213	0.268	1.610	13.55	13.10	13.30	115.0
Min		4810	9,550	1249	2.91	10.14	0.0199	0.0396	0.0172	0.241	1.335	13.40	11.80	12.85	113.0
Avg		5231	10,283	1395	3.01	11.35	0.0215	0.0420	0.0190	0.250	1.483	13.50	12.50	13.04	114.1
1	Variable Dilution	330	590	100.0	0.230	0.80	0.0182	0.0394	0.0222	0.310	1.700				143.5
2		345	575	107.8	0.230	0.80	0.0190	0.0378	0.0235	0.305	1.670				137.0
3		355	590	123.2	0.220	0.80	0.0200	0.0394	0.0273	0.296	1.695				140.0
4		340	575	115.2	0.230	0.80	0.0186	0.0377	0.0251	0.305	1.665				136.4
Max		355	590	123.2	0.230	0.80	0.0200	0.0394	0.0273	0.310	1.700				143.5
Min		330	575	100.0	0.220	0.80	0.0182	0.0377	0.0222	0.296	1.665				136.4
Avg		343	583	111.6	0.228	0.80	0.0190	0.0386	0.0245	0.304	1.683				139.2

Note: Variable dilution concentration values are not adjusted for diluent air contamination.
Mass emissions values as lb/mi are adjusted for influence of background.

TABLE A.5. SUMMARY OF CLASS II EXHAUST EMISSIONS UNDER 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID
Date: August 7 & 8, 1968

Cycle: Federal
Sampler: Continuous System
Fuel: Indolene

Run No.	Emissions	Cold Cycle, Avg	Hot Cycle, Avg	Weighted Composite, Avg
1	HC, ppm	314.55	351.76	338.7
	CO, %	2.66	2.67	2.67
2	HC, ppm	326.45	352.20	343.8
	CO, %	2.55	2.69	2.64
3*	HC, ppm	360.86	361.72	360.7
	CO, %	2.71	2.83	2.79
4	HC, ppm	340.87	358.77	352.5
	CO, %	2.77	2.83	2.81

*Most representative four-cycle concentration run data presented in Table 6 of this appendix.

TABLE A.6. CLASS II EXHAUST EMISSIONS - UNDER THE 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE
(Representative Mode Data, Run 3)

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6
Date: August 8, 1968

Cycle: Federal
Sample: Continuous System
Fuel: Indolene

Mode	HC	CO	CO_2	Cor Fac	HC Cor	CO Cor	HC Wid	CO Wid
Cycle No. 1								
1	300	5.80	11.50	1.022	300.60	5.812	10.82	0.2092
2	155	0.35	14.20	1.005	155.78	0.352	13.86	0.0313
3	105	0.30	13.45	1.063	111.62	0.319	28.69	0.820
4	120	0.35	13.95	1.025	123.00	0.359	10.95	0.320
5	185	1.30	14.50	0.995	184.08	1.294	8.65	0.0608
6	155	0.45	14.50	0.983	152.37	0.442	13.56	0.0393
7	220	7.40	10.60	1.025	225.50	7.585	63.82	2.1466
8	155	0.50	14.50	0.983	152.37	0.492	13.56	0.0438
9	5110	3.75	6.05	1.621	8283.31	9.807	173.95	0.2059
Total							337.86	2.851
Cycle No. 2								
1	300	5.80	11.50	1.002	300.60	5.812	10.82	0.2092
2	185	0.45	14.50	0.984	182.04	0.443	16.20	0.0394
3	120	0.30	13.70	1.046	125.52	0.314	32.26	0.0807
4	165	0.35	14.50	0.905	162.52	0.345	14.47	0.0307
5	210	1.55	14.20	0.965	202.65	1.496	9.52	0.703
6	175	0.60	14.50	0.978	171.15	0.587	15.23	0.0522
7	210	7.25	10.60	1.017	213.57	7.373	60.44	2.0866
8	165	0.55	14.80	0.959	158.24	0.527	14.08	0.0469
9	5060	3.65	6.20	1.608	8136.48	3.679	170.87	0.0773
Total							343.89	2.693
Average Cold Cycle Concentration							360.87	2.706
Cycle No. 3								
1	375	6.45	11.00	1.011	379.13	6.521	13.65	0.2348
2	230	0.55	14.50	0.979	225.17	0.538	20.04	0.0479
3	120	0.30	13.70	1.045	125.40	0.314	32.23	0.0807
4	175	0.55	14.50	0.980	171.50	0.539	15.26	0.0480
5	195	1.50	13.95	0.986	192.27	1.479	9.04	0.0695
6	175	0.60	14.50	0.976	170.80	0.586	15.20	0.0522
7	230	7.40	10.60	1.010	232.30	7.474	65.74	2.1151
8	175	0.55	14.50	0.979	171.33	0.538	15.25	0.0479
9	5070	3.70	6.00	1.638	8304.66	6.061	174.40	0.1273
Total							360.81	2.823
Cycle No. 4								
1	375	6.45	11.00	1.013	379.88	6.534	13.68	0.2352
2	210	0.70	14.50	0.974	204.54	0.682	18.20	0.0607
3	120	0.30	13.70	1.045	125.40	0.314	32.23	0.0807
4	175	0.50	14.50	0.981	171.68	0.491	15.28	0.0437
5	220	1.70	14.20	0.961	211.42	1.634	9.94	0.0768
6	185	0.60	14.50	0.976	180.56	0.586	16.07	0.0522
7	245	7.40	10.60	1.010	247.45	7.474	70.03	2.1151
8	195	0.70	14.50	0.975	190.13	0.683	16.92	0.0608
9	5050	3.60	6.05	1.550	7827.50	5.580	164.38	0.1172
Total							356.73	2.842
Average Hot Cycle Concentration							361.72	2.832

Four-Cycle Composite Emissions:
Hydrocarbons: 360.7 ppm.
Carbon Monoxide: 2.78.

TABLE A.7. CLASS II EXHAUST EMISSIONS UNDER 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1968 Chevrolet Stake
Engine: 250 CID, I-6
Date: August 7 & 8, 1968

Sampler: Variable Dilutions
Cycle: Federal
Fuel: Indolene

Run No.	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
1	150	275	154	0.230	0.80	0.00600	0.01200	0.0219	0.199	1.090	77.0
2	160	300	146	0.165	0.81	0.00638	0.01270	0.0206	0.141	1.088	79.2
3	170	300	146	0.160	0.80	0.00665	0.01240	0.0201	0.134	1.050	76.0
4	150	300	146	0.170	0.80	0.00552	0.01250	0.0203	0.143	1.060	78.0
Max	170	300	154	0.230	0.81	0.00665	0.01270	0.0219	0.199	1.090	79.2
Min	150	275	146	0.160	0.80	0.00552	0.01200	0.0201	0.134	1.050	76.0
Avg	158	294	148	0.181	0.80	0.00614	0.01240	0.0207	0.154	1.072	77.6

Note: Variable dilution concentration values are not adjusted for diluent contamination. Mass emission values as lb/mi are adjusted for influence of background air.

APPENDIX B

CLASS IV TRUCK RESULTS FOR THE 1970 HEAVY-DUTY GASOLINE TRUCK CYCLE

TABLE B.1. SUMMARY OF CLASS IV EXHAUST EMISSIONS UNDER 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1967 Chevrolet Stake
Engine: 366 CID, V-8
Date: July 22 and 23, 1968

Sampler: Continuous System
Cycle: Federal
Fuel: Indolene

Run No.	Emissions	Cold Cycle, Avg	Hot Cycle, Avg	Weighted Composite, Avg
1*	HC, ppm	277.49	231.09	247.00
	CO, %	1.61	1.419	1.48
2	HC, ppm	263.93	205.90	225.70
	CO, %	1.66	1.50	1.55
3	HC, ppm	278.11	197.21	225.40
	CO, %	1.69	1.61	1.64
4	HC, ppm	258.48	254.99	256.00
	CO, %	1.52	1.37	1.42

*Most representative four-cycle concentration run data presented in Table B.2 of this appendix.

TABLE B.2. CLASS IV EXHAUST EMISSIONS UNDER THE 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE (Representative Mode Data Run #1)

Vehicle: 1967 Chevrolet Stake
Engine: 366 CID, V-8
Date: July 22, 1968

Cycle: Federal
Sample: Continuous System
Fuel: Indolene

Mode	HC	CO	CO_2	Cor Fac	HC Cor	CO Cor	HC Wid	CO Wid
Cycle No. 1								
1	60	8.95	09.2	1.060	63.60	9.487	2.29	0.3415
2	155	1.60	14.2	0.965	149.58	1.544	13.31	0.1374
3	110	0.35	14.2	1.008	110.88	0.353	28.50	0.0907
4	130	1.53	14.2	0.970	126.10	1.484	11.22	0.1321
5	105	1.30	14.5	0.959	100.70	1.247	4.73	0.0586
6	120	1.40	14.2	0.972	116.64	1.361	10.38	0.1211
7	145	1.60	14.2	0.967	140.22	1.547	39.68	0.4378
8	130	2.00	14.2	0.954	124.02	1.908	11.04	0.1698
9	5900	4.01	7.01	1.355	7994.50	5.434	167.88	0.1141
Total							289.03	1.603
Cycle No. 2								
1	60	8.95	09.2	1.060	63.60	9.487	2.29	0.3415
2	140	1.65	14.2	0.965	135.10	1.592	12.02	0.1417
3	95	0.35	14.2	1.009	95.86	0.353	24.64	0.0907
4	120	1.50	14.5	0.950	114.00	1.425	10.15	0.1268
5	70	1.70	14.8	0.928	64.96	1.578	3.05	0.0742
6	110	1.50	14.5	0.950	104.50	1.425	9.30	0.1268
7	135	1.53	14.5	0.952	128.52	1.457	36.37	0.4123
8	130	1.80	14.5	0.940	122.20	1.692	10.88	0.1506
9	4800	4.74	06.4	1.560	7488.00	7.394	157.25	0.1553
Total							265.95	1.620
Average Cold Cycle Concentration							277.49	1.611
Cycle No. 3								
1	270	6.75	11.25	0.990	267.30	6.683	9.62	0.2406
2	130	1.75	14.20	0.963	125.19	1.685	11.14	0.1499
3	75	0.45	14.50	0.982	73.65	0.442	18.93	0.1136
4	105	1.55	14.70	0.936	98.28	1.451	8.75	0.1291
5	50	1.00	14.50	0.965	48.25	0.965	2.27	0.0454
6	105	1.55	14.50	0.950	99.75	1.473	8.88	0.1311
7	130	1.33	14.30	0.970	126.10	1.290	35.69	0.3651
8	110	1.80	14.50	0.943	103.73	1.697	9.23	0.1510
9	4200	4.62	7.15	1.417	5951.40	6.547	124.98	0.1375
Total							229.49	1.463
Cycle No. 4								
1	270	6.75	11.25	0.990	267.30	6.682	9.62	0.2406
2	120	1.70	14.30	0.956	114.72	1.625	10.21	0.1446
3	75	0.35	14.50	0.985	73.88	0.345	18.99	0.0887
4	95	1.50	14.50	0.950	90.25	1.425	8.03	0.1268
5	55	0.80	14.80	0.954	52.47	0.763	2.47	0.0359
6	108	1.35	14.50	0.975	105.30	1.316	9.37	0.1171
7	130	1.25	14.80	0.940	122.20	1.175	34.58	0.3325
8	110	1.70	14.50	0.945	103.95	1.607	9.25	0.1430
9	4350	4.19	7.30	1.425	6198.75	5.971	130.17	0.1254
Total							232.69	1.355
Average Hot Cycle Concentration							231.09	1.409

Four-Cycle Composite Emissions:
Hydrocarbons: 247.
Carbon Monoxide: 1.48.

TABLE B.3. CLASS IV EXHAUST EMISSIONS UNDER 1970 FEDERAL HEAVY-DUTY GASOLINE TRUCK PROCEDURE

Vehicle: 1967 Chevrolet Stake
Engine: 366 CID, V-8
Date: July 22-23, 1968

Sampler: Variable Dilution
Cycle: Federal
Fuel: Indolene

Run No.	HC/IR, ppm C	HC/FIA, ppm C	NO_x, ppm	CO, %	CO_2, %	HC/IR, lb/mi	HC/FIA, lb/mi	NO_x, lb/mi	CO, lb/mi	CO_2, lb/mi	Exhaust Flow, SCF/mi
1	310	535	215	0.170	1.6	0.00999	0.0244	0.0329	0.157	2.320	166
2	300	500	148	0.150	1.8	0.01150	0.0223	0.0273	0.135	2.550	171
3	270	465	214	0.155	1.4	0.01030	0.0210	0.0231	0.141	2.010	138
4	260	460	185	0.155	1.5	0.00990	0.0207	0.0278	0.142	2.165	142
Max	310	535	215	0.170	1.8	0.01150	0.0244	0.0329	0.157	2.550	171
Min	260	460	148	0.150	1.4	0.00990	0.0207	0.0231	0.135	2.010	138
Avg	285	490	191	0.158	1.6	0.01042	0.0221	0.0278	0.144	2.261	154

Note: Variable dilution concentration values are not adjusted for diluent air contaminations. Mass emission values as lb/mi are adjusted for influence of background air.